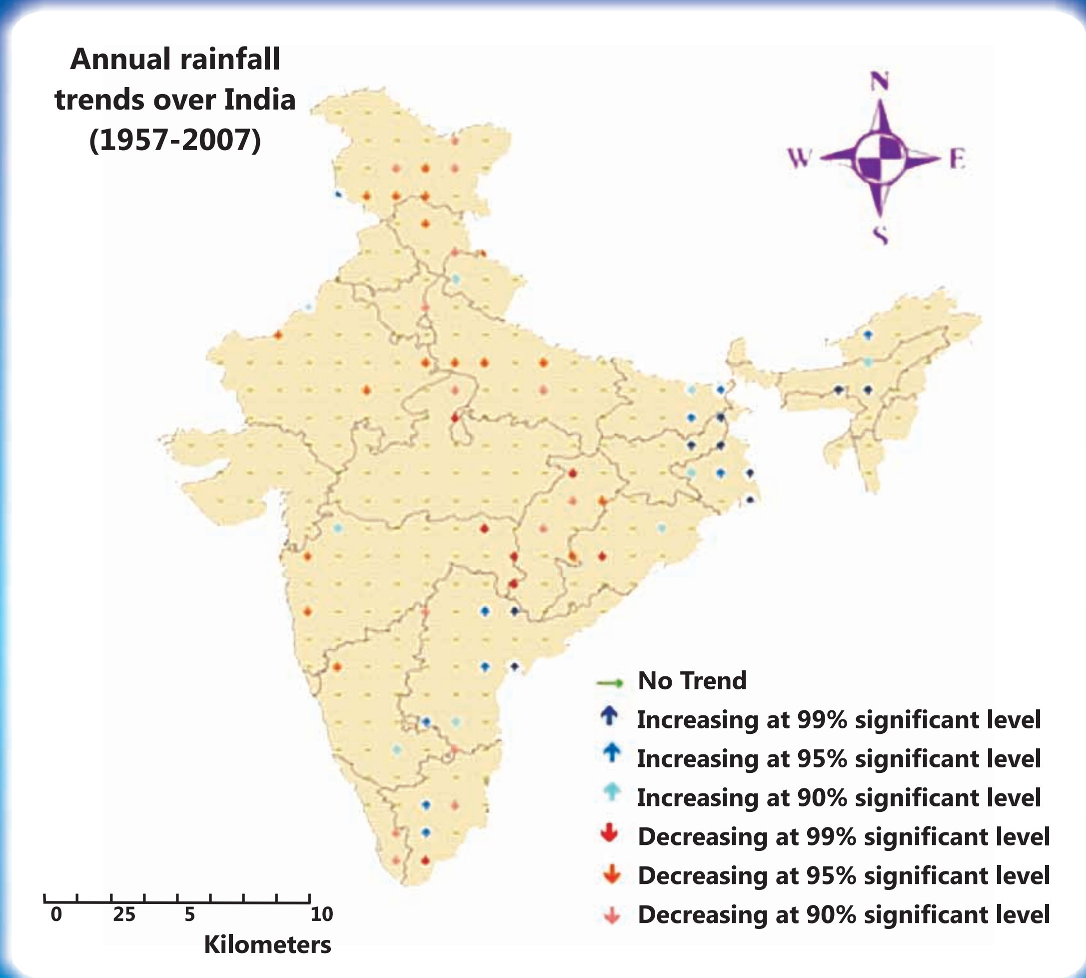

For further details contact:

Dr. B. Venkateswarlu
Director, CRIDA
vbandi_1953@yahoo.com

Dr. V.U.M. Rao
Project Co-ordinator (Agromet)
vumrao54@yahoo.com

Dr. S. Naresh Kumar
National Co-ordinator, IARI, New Delhi
nareshkumar.soora@gmail.com

Central Research Institute for Dryland Agriculture
Santoshnagar, Hyderabad - 500 059
Website: www.crida.ernet.in
Phone: 040-24530177, 040-24531802, Email: climatechange.crida@gmail.com

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ANNUAL REPORT 2009-10

Annual Report 2009-10

ICAR Network Project
on

Impact, Adaptation and Vulnerability of Indian Agriculture to Climate Change

Central Research Institute for Dryland Agriculture
Santoshnagar, Hyderabad - 500 059, AP, India

ICAR Network Project

on

Impact, Adaptation and Vulnerability of Indian Agriculture to Climate Change

Annual Report
2009 - 10

Co ordinating Center

Indian Agricultural Research Institute

New Delhi

भाकृअनुप
ICAR

Central Research Institute for Dryland Agriculture

Santoshnagar, Hyderabad – 500 059, Andhra Pradesh

CONTENTS

Coordinating Institute

Indian Agricultural Research Institute

New Delhi 110 012

Department / Division

Division of Environmental Sciences

Principal Investigator

Dr. P.K. Aggarwal

National Professor

Objectives

- To quantify the sensitivities of current food production systems to different scenarios of climatic change by integrating the response of different sectors
- To quantify the least-risk or 'no regrets' options in view of uncertainty of global environmental change which would also be useful in sustainable agricultural development
- To determine the available management and genetic adaptation strategies for climatic change and climatic variability
- To determine the mitigation options for reducing global climatic changes in agro-ecosystems

Executive Summary

- Past weather was analysed to delineate the changes and found an increasing trend in annual rainfall, and minimum temperature while decreasing trend for annual maximum temperature in parts of Bihar, West Bengal and Gujrat. However, in parts of UP, monsoon and annual rainfall declined at the rate of 7.8 and 12.2 mm/year, respectively. In Punjab, the annual and seasonal minimum temperature increased over the past three decades at the rate of 0.02-0.07 ^{o}C/year. The analysis of past 108 years rainfall data at Ludhiana revealed that the annual, *kharif* and summer season rainfall increased.
- Simulation analysis was carried out on the impact of climate change on sorghum and maize crops in India, adaptation strategies and net vulnerability at regional level. Irrigated *kharif* maize is projected to reduce yields by -6.83% in A1b 2030 scenario. This adverse effect of climate change is projected to be even higher in 2080 scenarios ranging from ~-14% in B2 scenario to about -25% in A1b and A2 scenarios. Adaptation strategies such as improved and tolerant variety managed under improved input efficiency with additional nitrogen fertilizer can improve the irrigated maize production by about 24% in A1b 2030 scenario. This adaption option can almost offset the negative impacts of climate change in A1b2080 scenario while can improve the yields marginally (3.5%) in A2 2080 scenario and substantially (~14.8%) in B2 2080 scenario.
- Global climate change may raise production of potato in Punjab, Haryana and western and central UP by 3.46 to 7.11% in A1b 2030 scenario, but in rest of India particularly West Bengal and plateau region potato production may decline by 4 to 16%. Such climatic changes are likely to result in increased soybean yields by 8-13%. Effect of climate change on groundnut is likely to be variable with yields varying between -5 and +7% as compared to current yields.
- Experiments conducted in field facilities such as Free Atmospheric CO_2 Enrichment (FACE) facility, Open Top Chambers (OTCs), Temperature Gradient Tunnels (TGTs) indicated that rise in atmospheric temperature (+1-3^{o}C) caused substantial reduction in yield of rice, groundnut and wheat at varying nitrogen levels. The elevated CO_2 level (560ppm) enhanced the biomass and economic yield of rice, groundnut and wheat substantially at all nitrogen levels. Groundnut showed greater thermal sensitivity during post flowering growth phase than during pre-flowering growth phase.
- Adaptation experiments indicated that in coconut (2 hybrids and 3 cultivars), arecanut (5 cultivars) and cocoa (3 hybrids and 4 cultivars), application of additional fertilizer amount is required to reap the benefits of elevated CO_2.
- Studies conducted to evaluate the changes in quality of economic parts due to elevated CO_2 indicated a reduction protein content in rice and aroma in basmati rice. Alkali spreading value in the hybrid and female parent Pusa 6B decreased and hence the gelatinization temperature increased resulting in firmer cooked rice under high $CO_{2.}$
- Increase in storage temperature beyond 28^{o}C reduced the myristic acid content in arecanuts, thus causing reduction in quality. Proper storage facilities are required to offset the effects of likely rise in temperature in stores under climate change scenarios, in order to avoid the loss of post-harvest quality in arecanut.

- An increase of 0.5^oC in average temperature in 2006 in Delhi caused a slight decrease in brown plant-hopper population while 1-3^oC rise resulted in significant decline. Temperatures of 30^oC inhibited the growth of ancestral range of *Pseudomonas fluorescence*, whereas evolved lines could tolerate the higher temperatures of 40^oC. Impact of elevated CO_2 and temperature on morphology of *Trichoderma viride* and major soilborne pathogens (*Macrophomina phaseolina, Fusarium oxysporum.f.sp.ricini, Rhizoctonia solani* and *Sclerotium rolfsii*); Trichoderma *viride* (for antagonistic activity); *Pseudomonas* spp (for PGPR traits) were also assessed.

- Various studies conducted to estimate and reduce the GHG emissions from agriculture. Results indicate that the cumulative methane flux from rice culture increased from 22 to 59 kg ha^{-1}at 550 ppm CO_2 in FACE, while reduced nitrate concentration resulted in a significant decline in nitrous oxide emission. The *Azolla* and *Cyanobacteria* systems in combination indirectly minimized the global warming potential in flooded paddy. The methane emission rates were lower in aerobic, SRI and alternate wetting and drying systems than in conventional system.

- An inventory of GHG emission by Indian agriculture was developed for the base year 2000 during which Indian agriculture contributed 386.1 million ton (Tg) CO_2 eq. The agriculture sector primarily emitted CH_4 (14.7 Tg) and N_2O (137.3 thousand ton, Gg). The bulk of the GHG emission from the agriculture sector was from enteric fermentation (65%) followed by rice cultivation (23%) and the rest were contributed by manure management, burning of agriculture crop residue and application of N fertilizer to soil. Methane emission due to enteric fermentation in 2000 was estimated to be 10.1 Tg. Buffalo and indigenous cattle, which are the main milk-producing animals in the country, contributed 44% and 42% total methane emission from livestock sector. Cross bred cattle emitted 8% and the small ruminants emitted about 7% of methane. Methane emission due to rice cultivation was estimated to be 3.5 Tg. Continuously flooded rice emitted maximum methane (1111 Gg) followed by flood prone (827 Gg) and single aerated (598 Gg) rice cultivated areas. During 2000, Indian agriculture produced 137.3 Gg of N_2O-N. Nitrogenous fertilizer application contributed 68% of that emission followed by manure and crop residue. Because of increased use of N fertilizer, N_2O emission is also increased over the years.

- Simulation analysis indicated that the carbon sequestration in stems of coconut plantations in states like AP and Tamil Nadu is projected to reduce by about 10 and 31%, respectively in PRECIS A1B 2030 scenario. However, in Karnataka and Kerala climate change is projected to increase the C sequestration into stem by about 28% and 3%, respectively. At all India basis also, the C sequestration into is projected to increase by about 1% in 2030 A1b scenario.

- Carbon sequestration potential of agro-forestry in Bundelkhand region is estimated to be around 22.42 t C ha^{-1} and is likely to increase up to 35.78 t C ha^{-1} at end of rotation period. The tree biomass, soil carbon and carbon sequestration potential of the region in 2030 is projected to be 67.42, 35.36 and 72.77 million tones, respectively.

- Soil datasets for 117 soil series representing 60 agro-ecological sub-regions (AESRs) of the country are compiled in a user-friendly manner. Datasets on soil series, climate, land use and crop management were documented for use in Rothamsted C, Century C and InfoCrop simulation models. Simulation analysis indicated that an increase of 2.5^oC caused variable decrease in total organic carbon in different layers of soil.

- In the dairy sector, results indicate that lactating cows and buffaloes have higher body temperature and are unable to maintain thermal balance. Body temperature of buffaloes and cows producing milk is 1.5- 2^{o}C higher than their normal temperature, therefore more efficient cooling devices are required to reduce thermal load of lactating animals as current measures are becoming ineffective. The feed additives like fenugreek and mustard were able to decrease the methane levels.
- Studies conducted in marine fisheries sector indicate that the coastal upwelling index during southwest monsoon increased by nearly 50% from 1997 to 2007. The high concentration and increasing trend of Chl *a* during the monsoon can be beneficial to herbivorous small pelagics. It was fond that 35 villages in Raigad and Ratnagiri districts would be affected due to rise in sea level by 0.3 m. Fishermen attach maximum importance to wind direction and speed as the drivers of fish abundance and availability, followed by rainfall and temperature.
- The vulnerability index for the fisheries sector of West Bengal indicated that fisheries activity is more susceptible to climatic events. Studies on inland fisheries indicated that drought in West Bengal during 2009 affected 92% of the fish seed hatcheries due to deficit rainfall and high temperature in the state. Freshwater ponds became unusable due to salinity rise because of cyclone.
- In poultry sector, mortality due to heat stress, occurred at about 34°C, was significantly high in heavy meat type chickens (8.4%) as compared to light layer type (0.84%) and native type (0.32%) chickens. Increase in temperature from 31.6°C to 37.9°C decreased feed consumption by about 36% and egg production up to 7.5% in broiler breeders and up to 6.4% in commercial layers as compared to their standard egg production percentages. The critical body temperature at which the birds succumb to death was 45°C which was observed at the shed temperature of 42°C. The naked neck birds performed significantly better than the normal birds with respect to thermo-tolerance, growth, feed efficiency and immunity in high temperatures as compared to normal broilers. The sperm viability and fertilizing ability, and live sperm counts were significantly reduced during high ambient temperature.
- Indigenous Technical Knowledge available in different agro-climatic zones is being collected and documented.
- Several network-centers have conducted the awareness programme on climate change for farmers, agricultural extension workers and KVK staff.

Signature of the Principal Investigator

Name : P.K. Aggarwal

Designation: Network Coordinator and National Professor

Specific Objectives of the Individual Centers

Indian Agricultural Research Institute, New Delhi

- To assess the impact of elevated temperature and CO_2 on growth, yield and quality of rice, groundnut and wheat under different N levels.
- Adaptation strategies to minimize the climatic risk in different crops through crop/varietal selection, fertilization, irrigation and planting scheduling etc.
- Assessing impact of climate change on pest dynamics and crop-pest interactions and linking pest population dynamics simulation models with InfoCrop model
- To assess the impact of elevated temperature and carbon dioxide on emissions of GHGs and preparation of inventory of CO_2 emission from crop residue burning and their mitigation from soils
- Assessing the impact of high temperature on evolution/adaptation of microbial population

Central Research Institute for Dryland Agriculture, Hyderabad

- To assess the impact of climate change on major food crops *viz.,* maize and rice in Andhra Pradesh
- To develop adaptation strategies and quantifying of the vulnerability in Andhra Pradesh
- Extreme event analysis and trends of rainfall and temperature for Andhra Pradesh
- To assess the impact of elevated CO_2 on major soil-borne pathogens
- Understanding the adaptation mechanisms in major pathogens and biocontrol agents against elevated CO_2 and temperature
- Impact of elevated carbon dioxide and cropping on soil organic carbon pools and nutrient status

Central Plantation Crops Research Institute, Kasaragod

- Effect of elevated temperature and CO_2 on response of coconut, arecanut and cocoa seedlings
- Adaptation strategies for coconut plantations to climate change scenarios in different agro-climatic zones
- Impacts on quality of post harvest produce
- Carbon trade potential of new coconut plantations as mitigation option

Indian Institute of Horticultural Research, Bangalore

- To documented information on indigenous technical knowledge relevant to climatic variability and climatic change in Karnataka.
- To create awareness of the farmers about the climate change and its impact on horticultural crops.
- To calibrate and validate InfoCrop models and using the models for impact assessment studies.

- To assess the impact of flooding and water stress on growth and yield of onion and tomato.
- To assess the impact of climate change under different scenarios on fruit quality and phenology of wine grapes.
- To quantify influence of extreme weather events on phenology of Mango.

Central Soil and Water Conservation Institute, Dehradun

- To provide first estimate of impact of climate change (runoff, soil loss) on important commodities of selected watersheds of India based on literature review and expert judgment.
- To calibrate and validate AVSWAT/Info Crop model for runoff, soil loss for key food crops in different Watersheds of the country.
- To simulate the impacts of different scenario of climate change (runoff and soil loss) on crop production through GLP/optimization.
- To quantify the suitability of various Watershed Management Measures for adaption to climate change (runoff and soil loss).

ICAR Research Complex for Eastern Region, Patna

- To calibrate and validate Infocrop model for key food crops in different agro climatic regions of Bihar.
- To simulate the impacts of different scenarios of climate change on crop production in Bihar.
- To quantify the suitability of various agronomic and land and water management measures for adaptation to climate change.
- To develop integrated modeling framework for coupling hydrologic model with crop water demand, water allocation and socio-economic models.

National Dairy Research Institute, Karnal

- Thermal stress mitigation in cattle and buffaloes.
- To measure influence of milk production level on methane emission from dairy animals.
- Methane mitigation on the basis of Indigenous Technical Knowledge.
- Adaptation of livestock to CC: Role of HSP's.

Central Marine Fisheries Research Institute, Cochin

- To conduct basic, applied and strategic research for quantifying the region – specific vulnerability of Indian marine fisheries to increasing climatic variability and climate change;
- To develop adaptation strategies for minimizing their negative impacts; and
- To identify mitigation strategies

Central Inland Fisheries Research Institute, Barrackpore

- Impact assessment of extreme climate (drought) on the growth, breeding and culture practices of fresh water carps.

- Development of composite vulnerability Index for Inland fisheries in various districts of West Bengal in relation to climate changes.
- Use of GIS for organization and display of spatial data on water resources of vulnerable areas of West Bengal.
- Selection of adaptive fish culture practices & fish species.

Tamil Nadu Agricultural University, Coimbatore

- Developing optimal land use pattern for different ACZs using the concept of different cropping systems followed in Tamil Nadu in current and future climate change scenarios.
- Documenting the weather related Indigenous Technical Knowledge (ITK).
- Training programme to farmers on climate change awareness and its effects on agriculture.
- Assessing the magnitude of change in temperature and rainfall over Tamil Nadu region up to 2100.
- Assessing the phonological response of rice, maize and sorghum to elevated temperature using temperature gradient tunnel.
- Mapping the hydrology of major river basins of Tamil Nadu for changing climate.
- Construction of methane inventory for agro ecosystems.

  Developing mitigation methodologies to minimize methane evolution from flooded paddy.

Bidhan Chandra Krishi Viswavidyalaya, Mohanpur

- To collect information on climate change related ITK.
- The climatic trend analysis for different stations under different agro-climatic regions of West Bengal.
- To find out the impact of climate change on growth and yield of Kharif rice, mustard and wheat.
- To work out the adaptation strategies in view of climate change.

National Bureau of Soil Survey and Land Use Planning, Nagpur

- Identify and use data sets in the Benchmark (BM) soils and in the Long-term Fertilizer Trial sites to estimate and predict carbon reserves.
- To update soil information for INFOCROP and soil carbon models.
- To correlate the carbon reserve and its changes with climate change.
- Quantify the impact of defined changes in land use and management options on carbon sequestration in soils and GHG emissions with a view to assist in the formation of improved policies to optimise resource use in the BM soil spots and in the LTFT sites.

Central Potato Research Institute, Shimla

- Simulation of impact of climate change on potato in India.
- Quantify suitability of agronomic measures in potato for adaptation.
- Compilation of indigenous traditional knowledge to overcome climatic extremes.

National Research Centre for Agroforestry, Jhansi

- Compendium of ITK related to agroforestry and climate change in Bundelkhand region.
- Carbon sequestration potential of agroforestry practices in Bundelkhand region.
- Organizing farmers' fare/Kishan Gosthi to senitize farmers about climate change.

Central Soil Salinity Research Institute, Lucknow

- To study the climate scenario of Indo-Gangetic belt.
- To study the impact of climate change on wheat yield under sodic soil condition in Central Uttar Pradesh.
- To study the carbon sequestration potential of different land use systems.
- To calibrate and validate the InfoCrop model under sodic environment.
- To conduct an awareness programme.
- Integration of indigenous traditional knowledge with new technologies for betterment of farmers.

ICAR Research Complex for NEH Region, Barapani

- Collection and documentation of ITKs relevant to climatic variability and agriculture in NEH region.
- Studying the detail scenario of climate change in North East India.
- Soil analysis for C balance from agro-ecological zones of Meghalaya.
- Trend analysis of Weather data and land use change in Meghalaya.
- To estimate C-sequestration & GHG mitigation potential & cost in NEH region.
- Adaptation strategies to climate change.

Project Directorate on Poultry, Hyderabad

- To assess the impact of climate change on egg production, growth, health and survivability of poultry.
- To document Indigenous knowledge in relation to climate change relevant to poultry production.
- To identify various managemental and nutritional strategies for adaptation to climate change.

Tocklai Experimental Station, Tea Research Association, Jorhat

- To study the effect of elevated CO_2 and temperature on tea biomass production and quality of different tea cultivars.
- To quantify the potential and cost of carbon sequestration in conventional and organic tea gardens.
- To identify the potential adaptation strategies and subsequently evaluate them in terms of yield, quality and carbon sequestration.
- To raise awareness among tea growers about the climate change scenarios.
- To analyze and document the concepts of ITK to mitigate impacts of climate change in sustainable tea production.
- To prepare the assessment report of climate change impact, vulnerability and adaptation to climate change in North Eastern India.
- To validate the CUPPA-tea model in N-E India (Optional).

Anand Agricultural University, Anand

- To provide a first estimate of impact of climate change on important crops based on literature review and expert judgment.
- To calibrate and validate InfoCrop model for key food crops (maize, paddy, pearl millet and wheat) in different agro-climatic regions of the state.
- To simulate the impacts of different scenarios of climate change on crop production.
- To quantify the suitability of various agronomic measures for adaptation to climate change.

Directorate of Soybean Research, Indore

- Calibration and validation of InfoCrop model for major crops of M.P.
- Spatial and temporal assessment of production potential of major crops of MP under present and future climate scenarios.
- Analysis of physiological processes (phenology, growth, pollen sterility, grain development) affected by / associated with climate change.
- Assessment/identification of adaptation strategies to mitigate the adverse impact of climate change.

Indian Institute of Sugarcane Research, Lucknow

- To provide an estimate of impact of climate change on sugarcane in states of Uttar Pradesh and Maharashtra based on literature review.
- To calibrate and validate DSSAT and WOFOST models for sugarcane.
- To develop sugarcane simulation module with INFOCROP frame work.
- To quantify the suitability of various agronomic measures for adaptation to climate change.
- To collect and compile relevant indigenous traditional knowledge on sugarcane crop.

Punjab Agricultural University, Ludhiana

- To provide a first estimate of impact of climate change on important commodities based on literature review and expert judgement.
- To calibrate and validate InfoCrop model for key food crops in different agroclimatic regions of the state.
- To simulate the impact of different scenarios of climate change on crop production.
- To quantify the suitability of various agronomic measures for adaptation to climate change.
- To examine the relationship between the impact of climate change on production / availability and food vulnerability in different economic groups.

CSK Himachal Pradesh Agriculture University, Palampur

- Impact of climate change scenarios on rice productions and adaptations measures simulated for late sown Wheat and Rice.
- Demonstration studies for verifications of simulated adaptations for Maize and Mustard.
- Impact of climate change on Tea production under sub humid sub temperate climate of Himachal Pradesh.
- Impact of climate change on water inflow of major rivers of Himachal Pradesh.
- Validation of Local traditional knowledge of climate and weather.
- Climate literacy among stakeholders.

Executive Summary by Different Centres

Indian Agricultural Research Institute, New Delhi

- Simulation analysis was carried out on the impact of climate change on sorghum and maize crops in India, adaptation strategies and net vulnerability at regional level. Irrigated *kharif* maize is projected to reduce yields by -6.83% in A1b 2030 scenario. This adverse effect of climate change is projected to even higher in 2080 scenarios ranging from ~-14% in B2 scenario to about -25% in A1b and A2 scenarios. Improved and tolerant variety managed under improved input efficiency with additional nitrogen fertilizer can improve the production by about 24% in A1b 2030 scenario. This adaption option can almost offset the negative impacts of climate change in A1b2080 scenario while can improve the yields marginally (3.5%) in A2 2080 scenario and substantially (~14.8%) in B2 2080 scenario. On the other hand, rainfed *kharif* sorghum production is likely to benefit by about 2.5% in A1b and B2 scenarios of climate change while the positive impacts are projected to be even higher (~21.5%) in A2 2080 scenario at all India level. In case improved variety is managed with improved input efficiency and provided with additional nitrogen fertilizers, the rainfed sorghum production can be increased in the range of 6 to 34% in different scenarios.
- An inventory of GHG emission by Indian agriculture was developed for the base year 2000 during which Indian agriculture contributed 386.1 million ton (Tg) CO_2 eq. The agriculture sector primarily emitted CH_4 (14.7 Tg) and N_2O (137.3 thousand ton, Gg). The bulk of the GHG emission from the agriculture sector was from enteric fermentation (65%) followed by rice cultivation (23%) and the rest were contributed by manure management, burning of agriculture crop residue and application of N fertilizer to soil. Methane emission due to enteric fermentation in 2000 was estimated to be 10.1 Tg. Buffalo and indigenous cattle, which are the main milk-producing animals in the country, contributed 44% and 42% total methane emission from livestock sector. Cross bred cattle emitted 8% and the small ruminants emitted about 7% of methane. Methane emission due to rice cultivation was estimated to be 3.5 Tg. Continuously flooded rice emitted maximum methane (1111 Gg) followed by flood prone (827 Gg) and single aerated (598 Gg) rice cultivated areas. During 2000, Indian agriculture produced 137.3 Gg of N_2O-N. Nitrogenous fertilizer application contributed 68% of that emission followed by manure and crop residue. Because of increased use of N fertilizer, N_2O emission is also increasing over the years.
- Rise in atmospheric temperature (+1-3°C) caused substantial reduction in yield of rice, groundnut and wheat at varying nitrogen levels, The reduction in biomass and yield was mainly due to marked reduction in their yield attributes.
- Contrary to this, elevated CO_2 level (560 ppm) in the air enhanced the biomass and economic yield of rice, groundnut and wheat substantially at low medium and high nitrogen levels, which was mainly attributed to marked increase in photosynthetic rate, chlorophyll content and yield attributes of these crops.
- Groundnut showed greater thermal sensitivity during post flowering growth phase than during pre-flowering growth phase. However elevated temperature throughout the entire growth phase showed additive effect of high thermal stress during vegetative and reproductive growth phases.

- Protein content in rice grain reduced markedly under elevated CO_2 condition at all nitrogen levels.
- Aroma in basmati rice grains declined under higher levels of CO_2. Alkali spreading value in the hybrid and female parent Pusa 6B decreased and hence the gelatinization temperature increased thus resulting in firmer cooked rice under high CO_2.
- An increase of 0.5 ^oC in average temperature over 2006 Delhi weather showed a slight decrease in brown plant hopper population while 1.0 - 3^oC rise resulted in appreciable decline in it. In accordance with decline in BPH population, yield loss due to the pest showed a declining trend with intensity of climate change.
- The cumulative methane flux in rice grown under 550 ppm CO_2 in FACE increased from 22 to 59 kg ha^{-1}. Reduced nitrate concentration was observed in rice soil under elevated carbon dioxide concentration in FACE, which resulted in a significant decline in nitrous oxide emission as compared to ambient carbon dioxide levels.
- The radiation extinction coefficient (k) values for both genotypes of pigeon pea were smaller for plants exposed to elevated CO_2 which indicated a more erect structure for these plants. However, the radiation use efficiency (RUE) was greater for elevated CO_2 grown plants than the ambient CO_2 plants. Pigeon pea plants under elevated CO_2 conditions showed lower stomatal resistance and hence more transpiration and lower leaf temperature. In genotype Pusa 992, seed yield increased by 12% due to elevated CO_2 exposure and in genotype PS 2009, it became inderminate type under elevated CO_2 levels and did not mature with undeveloped pods. But the significant increase in biomass did not translate into seed yield due to poor HI and less number of grains per pod under this condition. After the completion of the crop season, in rhyzopheric soil, all different active carbon pools (oxidizable organic carbon, carbohydrate carbon, labile carbon, total carbon and microbial biomass carbon) increased significantly due to CO_2 exposure.
- The high temperature of 30°C inhibited the growth of the ancestral range of *Pseudomonas fluorescens*, whereas evolved lines could tolerate the higher temperature of 40°C. These gains in evolution lines in term of growth rate as well as tolerance to temperature were not associated with decline in growth rate at the lower temperature.

Central Research Institute for Dryland Agriculture, Hyderabad

- Impact of elevated carbon dioxide and cropping on soil organic carbon pools and nutrient status were evaluated.
- Impact of elevated CO_2 and temperature on morphology of *Trichoderma viride* and major soil borne pathogens (*Macrophomina phaseolina*, *Fusarium oxysporum*. *F.sp.ricini*, *Rhizoctonia solani* and *Sclerotium rolfsii*) were assessed.
- Impact of elevated CO_2 and temperature on production of cellulase, chitinase and β 1-3 glucanase of *Trichoderma viride* was assessed.
- Effect of elevated CO_2 on in-vitro screening of *Trichoderma* isolate for their antagonistic activity by dual culture method and sclerotial parasitization was assessed.

- Impact of elevated CO_2 and temperature on the PGPR traits of *Pseudomonas* spp. was evaluated.
- In pigeon pea, the total biomass improved from 61.1 g/pl at ambient to 77.5 g/pl at 550 ppm and 116.9 g/pl under 700 ppm CO_2, there by showing an improvement of biomass by 26.8% and 91.3% at 550 ppm and 700 ppm, respectively.
- The pod number per plant showed an increase of 23.8% at 550ppm and 97.9% at 700ppm over ambient chamber control which was about two fold value as that obtained at 370ppm showing it to be an important yield contributing component. The flower to pod conversion and retention of flower as well as pods in pulses is sensitive to abiotic stresses like moisture, temperature and nutritional stresses there by reduction in sink size result in reduced grain yield. In the present study it was clearly evident that the enhanced levels of CO_2 significantly improved the number of pods and seeds translating into higher grain yield.
- The crop maintained a significant positive increase for HI at elevated CO_2 i.e. from 29.2% HI at 370ppm to 36.5% at 550ppm and 38.2% HI at 700ppm, thus showing an increment of 14% and 19.2% over ambient values. This was the resultant of a proportionate equal increment in total biomass and also grain yield under elevated CO_2.
- The present results indicate that under climate change scenario also redgram crop could sustain as all the yield components as well as the HI have shown significant increase under elevated CO_2.

Central Plantation Crops Research Institute, Kasaragod

- In order to study the effect of elevated temperature (+2°C) and CO_2 (550 and 700 ppm) on seedlings of coconut (2 hybrids and 3 cultivars), arecanut (5 cultivars) and cocoa (3 hybrids and 4 cultivars) are being grown in Open Top Chamber facility under different regimes of fertilizer and irrigation doses. Results indicated that, application of additional fertilizer amount is required in coconut, areca nut and cocoa to reap the benefits of elevated CO_2. Additional application of fertilizer dose enhanced crop performance in terms of net photosynthetic rates by 10 to 20%. However, more data needs to be generated for quantifying these benefits in terms of dry matter production. The seedling vigor increased in elevated CO_2 conditions with additional dose of fertilizer.
- Simulation analysis indicated that negative impacts of climate change on coconut plantations can be overcome by adaptation strategies such as assured irrigation through drip system coupled with soil moisture conservation and by providing fertilizers/nutrients through organic and inorganic source in doses higher than those currently applied by the farmers. Such measures also maximize the positive impacts of climate change. However, in states like Andhra Pradesh and Tamil Nadu, negative impacts of climate change can be minimized by intensive management of the plantation. This includes planting of improved and tolerant varieties (through population improvement).
- Influence of elevated temperature on the post-harvest quality of arecanut during storage was studied. Results indicate that increase in storage temperature beyond 28°C reduces the myristic acid content in arecanuts, thus causing reduction in quality. Proper storage facilities are required to offset the likely rise in temperature in stores under climate change scenarios, in order to avoid the post-harvest quality reduction in arecanut.

- Simulation analysis indicated that the carbon sequestration in stems of coconut plantations in states like AP and Tamil Nadu is projected to reduce by about 10 and 31%, respectively in PRECIS A1B 2030 scenario. However, in Karnataka and Kerala climate change is projected to increase the C sequestration into stem by about 28% and 3%, respectively. At all India basis also, the C sequestration is projected to increase by about 1% in 2030 A1b scenario.

Indian Institute of Horticultural Research, Bangalore

- Farmer's awareness programme on the Impact of Climate Change on Horticultural Crops was organised and about 150 farmers participated in the programme. An extension folder entitled "Climate change and its impact on horticulture" and its Kannada version were released.
- Calibration and validation of the InfoCrop model for onion was taken up. Though model is simulating the days to bulb initiation, days to maturity and yield levels for Dharwad and Hyderabad locations, the yield level predictions are low for Karnal and Hisar locations where onion in grown mainly in *rabi* season.
- In onion with 550 ppm CO_2 and water stress for seventeen days Agrifound Dark Red (ADR) recorded higher photosynthesis rate though there was a drastic reduction of 70.73% and 82.12% in ADR and Arka Kalyan, respectively in relation to non-stressed plants. After the recovery for 22 days the plants had attained normal photosynthesis rates. Water stress in caused reduction of more than 40.0% leaf area after two weeks and 53.0% after four weeks. Root growth was also more affected in Agrifound Dark Red (ADR).
- The flooding imposed at bulb initiation stage in onion showed that plants grown in raised beds recorded photosynthetic rate 6.0 - 16.0% higher than plants grown in channel after 6 days flooding. The bulb dry matter and bulb yield were higher in raised beds as compared to plants grown in the channel. The 6 days flooding was found to be critical at bulb initiation stage and cultivar ADR was affected more compared to Arka Kalyan. There was a decrease in anthocynin and FRAP (ferric reducing antioxidant potential) and increase in total flavnoids due to flooding. The raised bed cultivation may be adopted for onion in flood prone areas. In tomato cv Arka Ashish flooding caused reduction in photosynthetic rate of 42.0% at 24 h flooding and 58.3% at 48 h flooding in channel. While in raised bed the reduction was only 27.0% at 24 h flooding and 46.0% at 48 h flooding.
- Wine grape cultivars, Cabernet Sauvignon and Shiraz, in Bangalore and Nasik regions are already grown under high temperatures when compared to other growing areas. The extracted monthly data for different scenarios showed that in 2050 A1B scenario the increase in average temperature for Bangalore and Nasik regions are expected to be 2.46 and 2.84 ºC and in B2 2080 scenario 2.48 and 2.61ºC, respectively.
- In mango this year due to below average rainfall during the rainy months the moisture stress during October led to sporadic flowering. The normal flowering did not occur as the prevailing temperatures were 1ºC higher during the months of November and December. As the minimum temperatures dropped below 16ºC subsequently during the months of January and February flowering occurred late in February.

Central Soil and Water Conservation Research and Training Institute, Dehradun

- Spatial information *viz,* longitude, latitude, altitude, Climatic parameters viz rainfall, radiation index, evaporation, runoff, moisture index, aridity index, precipitation deficit etc. have been generated for the watershed under study using daily weather data of thirty years extracted from nearby meteorological stations through best possible spatial interpolation.
- In order to assess the impacts of climate change on hydrology and crop production of Navamota watershed in Gujarat, Monthly projections for the period of 2071-2100 and base line prediction of 1961-1990 from the Hadley Centre's general circulation model (HadCM3) appropriately downscaled by PRECIS model run for Indian condition (IITM, Pune) under the scenarios representing intermediate emissions (A2a, CO_2 = 867 ppm) were used to run SWAT and Info Crop model.
- The DEM has been derived from the ASTER 30 data and was appropriately processed to scale down to a higher spatial resolution. The actual stream derived from high resolution Google earth data was digitized and subsequently burnt on the DEM to exactly focus on the intended outlet.
- Information from published literatures, Land sat ETM 7 data merged with Google earth image has been used to classify the images and land use determination
- The crop databases used are as per the default database provided in SWAT model with some modifications based on available literatures. Heat units were exactly input as per the crop physiological needs
- The model was calibrated and validated using observed runoff data of the watershed from 1992-1996 and found to be reasonably good with acceptable model efficiency. The choice of calibration parameters was based on a rigorous model sensitivity analysis which provides relative ranking procedure to accept parameters important to watershed under study.
- Under the same cropping pattern and management activities, surface runoff and total sediment load, total aquifer recharge, Water yield, PET and ET are likely to increase by 49.5 percent, 99.6 percent, 19.5 percent, 27.8 percent, 6.4 percent and 7.0 percent respectively under projected condition with increase in rainfall by 16 percent.
- The percent increase in the cross section of the field bund in medium soil is expected to be 33.3, 71.1 and 113.3 percent more from the cross section during the base period of 1961-1990. Similarly the percent increase in the cross section of the field bund in light texture soil is expected to be 30.9, 65.5 and 103.6 percent more from the cross section during the base period of 1961-1990.

ICAR Research Complex for Eastern Region, Patna

- An increasing trend in annual rainfall, and minimum temperature while decreasing trend for annual maximum temperature was observed for all stations. On an average number of days with temperature more than or equal to 40^0C and days with minimum temperature less than or equal to 10^0C decreased after 2000 for all stations.

- Multiple regression analysis showed 33% variability in rice productivity was related with *kharif* season rainfall.
- Under B2 scenario station wise pooled data showed that yield of all varieties of rice decreased from baseline. Yield of wheat and *kharif* maize also showed decrease while an increase was observed for *rabi* maize.
- Transplanting the seedlings earlier than normal transplanting in rice increased the yield in all the three varieties for 2020, 2050 and 2080.
- There is decrease in stream flow during monsoon season under B2a emission scenario in all the three periods (2020, 2050 and 2080) whereas there is increase in stream flow during pre-monsoon season.

National Dairy Research Institute, Karnal

- The study conducted during summer and hot-humid period indicated that lactating cows and buffaloes have higher body temperature and are unable to maintain thermal balance.
- Body temperature of buffaloes and cows producing milk is 1.5- 2^{O}C higher than their normal temperature, therefore more efficient cooling devices should be used to reduce thermal load of lactating animals. Heat abatement devices like fan, mist cooling in use at present are unable to dissipate their body heat.
- The results indicated that fenugreek and mustard affect methane production in vitro at different concentrations and methane produced per unit of feed decreased with increase of fenugreek and mustard content in diet.
- The levels of feed additives were able to decrease methane levels in relation to doses used. The energy loss in methane declined due to addition of fenugreek and mustard without influencing quantity of total gas.

Central Marine Fisheries Research Institute, Cochin

- Studies on seasonal and inter annual changes in oceanographic features and their impact on small pelagic catches off Kerala showed that the catch of small pelagics, especially that of the oil sardine *Sardinella longiceps* has increased from 1,554 tonnes in 1994 to 2, 50, 469 tonnes in 2007 in the upwelling zone off Kerala (southwest coast of India).
- Time series data of different climatic and oceanographic parameters gathered from different sources showed that, during 1967-2007, the annual sea surface temperature increased by 0.15°C per decade; scalar and zonal wind speeds also increased during these four decades. The SST is increasing; the surface winds are strengthening and the coastal upwelling index during southwest monsoon increased by nearly 50% from 1997 to 2007.
- The high concentration and increasing trend of Chl *a* during the monsoon resulted increase in of over 200% in annual average Chl *a* concentration. The increasing CUI and Chl *a* during monsoon sustained an increasing catch of oil sardine during post-monsoon season. This trend indicates that the current warming is beneficial to herbivorous small pelagics.

- To find out the vulnerability of these fishing villages to sea level rise, validation of available primary data from vulnerable fishing villages along Maharashtra coast was completed by ground truth by using GPS. After geo-referencing these villages, three different SLR (Sea Level Rise) scenarios (0.3 m, 0.6 m and 1.0 m) were created to determine critical area adjacent to the coast, likely to be submerged. Among the 75 coastal villages that are located within 100 m from high tide line in five coastal districts (Thane, Mumbai, Raigad, Ratnagiri and Sindhudurg) of Maharashtra, it was found that 35 villages in Raigad and Ratnagiri districts would be affected due to rise in sea level by 0.3 m.
- Interview with 591 fishermen from the states of Maharashtra, Kerala and Chennai, has provided information on weather-related ITK of coastal fishermen and how best the ITK could be integrated for advancement of scientific research to evolve options to adapt to climate change. Fishermen attach maximum importance to wind direction and speed as the drivers of fish abundance and availability, followed by rainfall and temperature. They believe that direction and speed of wind and temperature have changed over the last 20 years, which will have adverse impact on fisheries.
- Sea erosion in Kerala and Tamilnadu, cyclones in Maharashtra and Tamilnadu and sea status off Maharashtra are perceived as major safety concerns. In the event of cyclones and sea erosion, fishermen of Tamilnadu prefer temporary exit from their villages; their counterparts in Kerala prefer temporary exit as well as permanent rehabilitations to interior dwellings.

Central Inland Fisheries Research Institute Barrackpore

- Drought condition prevailing in West Bengal during 2009 had impacted fisheries. District of North 24 Parganas rainfall was deficient by 29%, Bankura by 27%, Burdwan by 23% and Hooghly by 34% in the fish breeding months of March to September. The total number of 23 out of 25 i.e. 92% of the fish seed hatcheries were affected by the deficit rainfall and increasing trend of temperature in the state. That results indicate about 61% and 73% loss of fish seed in North 24 Parganas and Bankura, respectively during 2009 compared to the last four years average.
- The vulnerability index for the fisheries sector developed for 6 districts of West Bengal indicated that in most of the districts, fisheries activity is more susceptible to climatic events and adaptive capacity is less in terms of limited opportunities for occupational diversification.
- The impact of extreme event the cyclone *Aila* affected loss to human lives, properties, fishing equipments, agriculture and aquaculture enterprises. Freshwater fishes in ponds were rendered ineffective due to salinity rise. Adaptation options tried were stoking of these ponds with salt tolerant fish species with encouraging result.

Tamil Nadu Agricultural University, Coimbatore

- An MGLP model incorporating the cropping systems was developed and test verified with the data for Haryana given by National coordinator. For Tamil Nadu the prevailing major cropping systems are now identified and results will be given and validated for the next year.

- Indigenous Technical Knowledge relevant to Farmers of Tamil Nadu were collected and documented and the detailed reports were submitted to the National Coordinator.
- Future climate projection based on A1B scenario resulting from Regional climate model (PRECIS) experiment suggest that climate of the most part of Tamil Nadu will be warmer in all seasons and drier in dry season relative to current condition. Précis model A1B scenario projected mean annual temperature rise likely up to 4.4 over Tamil Nadu. Précis model run shows both increase and decrease in rainfall over Tamil Nadu into 21^{st} century.
- DSSAT model was employed to study the physiological response of maize and sorghum to elevated temperature and CO_2. The reduction in modeled maize yields is primarily attributed to temperature increases that shorten the crop growth period, particularly the grain-filling period. The projections showed that the mean aggregate production changes for maize and sorghum were –15% and –11%, respectively.
- Model simulation suggest that C_4 photosynthesis (Maize and sorghum) is already saturated at the current levels of atmospheric CO_2, and future increases in CO_2 (550 ppm) will not be effective at boosting productivity.
- The role of photosynthetic cyanobacteria and azolla in minimizing methane flux in flooded paddy was studied. The Azolla and Cyanobacteria systems in combination indirectly minimized the global warming potential in flooded paddy which was identified based on dissolved oxygen and redox potential measurement.
- The methane evolution rates from the different systems of rice cultivation aerobic, SRI and AWD were recorded. Aerobic, SRI and AWD recorded lowest emission rates (7.40, 7.80 and 7.95 mg CH_4 $m^{-2}h^{-1}$ respectively), while the emission rate was high in conventional system (8.80 mg CH_4 $m^{-2}h^{-1}$). Redox status of a flooded soil is an indirect indicator of methane flux pattern from rice ecosystem.

Bidhan Chandra Krishi Viswavidyalaya, Mohanpur

- Weather data of different stations of West Bengal were collected and analysed for maximum temperature, minimum temperature and rainfall trend. Most of the locations showed an increasing rainfall and temperature trend.
- InfoCrop model was used to work out the impact of changed climatic scenario on selected crops (*kharif* rice, mustard and wheat). In the New Alluvial zone of West Bengal, it was observed that if temperature is increased by 1°C, the yield decrease will be in the order of 830 kg/ha for *kharif* rice, 450 kg/ha for mustard and 640 kg/ ha for wheat.
- Attempt was also made to work out the adaptation strategies for climate change by changing sowing date. If temperature increased by 1°C, farmers should sow k*harif* rice at end of May, mustard at mid-October and wheat at late November to get optimum yield.

National Bureau of Soil Survey and Land Use Planning, Nagpur

- Soil datasets for 117 soil series representing 60 agro-ecological sub-regions (AESRs) of the country are compiled in a user-friendly manner.
- Datasets on soil series, climate, land use and crop management were documented for use in Rothamsted C, Century C and InfoCrop simulation models.
- Rothamsted C and Century C were evaluated for a few Long Term Fertilizer Trial sites. Observed trends in the total organic carbon (TOC) showed an increase in the manurial treatment in combination with recommended dose of fertilizers; TOC remained, however, almost similar over years for all other treatments. Akola LTFT was used to evaluate Century C model. Overall, Century modelled Akola trial well in tr1 (control), tr2 (50% NPK) and tr13 (100% NPK+FYM) with tr14 (only FYM) as an exception.
- InfoCrop model was evaluated in Kheri and Nabibagh for wheat-soybean crop rotation. Sole increase in temperature results in decline in yield of soybean and wheat when compared with a situation assuming business as usual. But when increase in temperature is coupled with increased concentration of CO_2 there is a significant improvement in soybean and wheat yield.
- Modelled TOC stocks in Kheri site was subjected to an increase of 2.5°C during 1990 to 2090. The percent fall in TOC content is more in single layer as compared to combination of 5 different layers. This shows that soil must be considered as an entity of different layers which will mitigate the effect of global warming due to increase in temperature.

Central Potato Research Institute, Shimla

- Simulation studies with InfoCrop-Potato model was done for impact analysis and adaptations to climate change scenarios A1B on potato production in India.
- Impact of climate change on potato production was found to be variable in different agro-ecological regions.
- Potato production in Punjab, Haryana and western and central UP may increase by 3.46 to 7.11%.
- In eastern UP and Bihar simple adaptation measures of minor changes in planting time was found effective to sustain production in future climate scenarios only with minor losses.
- In rest of India particularly West Bengal and plateau region potato production may decline by 4 to 16% in 2020 and 13 to 46% in 2050 with or without simple adaptations. These regions would require technological interventions of heat and water stress tolerant cultivars.

National Research Centre for Agroforestry, Jhansi

- Enumeration of all trees was done on farmlands, farm bunds, culturable wastelands etc. in Bundelkhand region.

- Classification of trees as slow, medium and fast growing depending upon their growth habit and MAI. The number of trees per hectare was estimated for slow, medium and fast growing trees per village and it was converted on block and district level basis.
- Base line was developed on the basis of Land use system, general information, above ground biomass and soil Organic Carbon in different districts.
- On an average tree biomass in 2010 was 22.36 t ha^{-1} in different districts of the region and after 21-years it would be 33.15 t ha^{-1}. The soil carbon in the beginning was 9.21 t C ha^{-1} and at end of rotation period the soil carbon would be 17.38 t C ha^{-1}. The crop biomass was higher in the beginning and it was reduced in subsequent year.
- Carbon sequestration potential varied in each districts depending upon tree density, growth and age of trees. In different districts, on an average, carbon sequestration in 2010 was 22.42 t C ha^{-1} and likely to increased up to 35.78 t C ha^{-1} at end of rotation period. The tree biomass, soil carbon and carbon sequestration potential of the region in 2030 would be 67.42, 35.36 and 72.77 million tones, respectively.
- The discounted cost at 15% discount rate varied from Rs. 175959 to 196837 per hectare in different districts of Bundelkhand region in period of 21-years. Similarly discounted benefit varied from Rs. 309732 to 312922 per hectare in different districts in the same period. The benefit: cost of agroforestry practices varied from 1.38 to 1.94 in different districts.

Central Soil Salinity Research Institute, Lucknow

- Climate scenario of three locations *viz.,* Lucknow, Kanpur and Faizabad were evaluated for temperature trend during the last thirty years (1980-2009). It indicated rising in maximum and minimum temperatures ranging from 0.15 to 1.22°C and 0.003 to 0.67°C, respectively. However, for rainfall a decreasing trend was recorded in recent years.
- Rise in temperature by 1°C in the month of March could reduce the wheat yield to about 8% under sodic soil conditions.
- The study showed that degraded sodic land hold promise to increase carbon through biological reclamation by planting agro forestry and horticultural trees. Carbon sequestration rate for *Prosopis juliflora* was 0.826 Mg ha^{-1} yr^{-1} and for rice- wheat systems it was 0.689 Mg ha^{-1} yr^{-1}.
- InfoCrop model was calibrated and validated for rice varieties *viz.* CSR 13 and CSR 23 under sodic soil conditions. The simulated grain yield compared well with the observed yield with the RMSE value of 0.421 for CSR 13 under transplanted condition and 0.264 and 0.529 for CSR 23 under transplanted and direct seeded conditions, respectively.
- An awareness programme with exhibition and questionnaire on global warming was arranged for farmers and students at research farm Shivari, Lucknow. It was found that 67% of farmers were aware of climate change and 62% said that rice and wheat crop is getting affected due to change in rainfall and temperature.

ICAR Research Complex for NEH Region, Barapani

- Most of the ITKs were based on the direction of wind, weather conditions, position of heavenly bodies as well as the behaviour of animals and plants, etc. as an indicator to forecast the weather/ climate related phenomena of that region. This knowledge was not only used for foretelling rainfall and other weather phenomenon, but also in determining the suitability of a land for cultivation as well as for advance planning in performing various agricultural operations by the farmers and other stakeholders in preparing decision making plan.
- Trend analysis of weather parameters through long term process shows a rising and declining trend of the climatic condition seasonally and annually. The average of 26 years of climatic water balance also reflects that except in the month of January (-70mm) there is a surplus of water (>500 mm) during the entire years. However, soil moisture status mostly remains below sufficiency level to support optimum crop growth during pre as well as post monsoon months. Only in monsoon months (June to September), soil moisture used to be above sufficiency level.
- Soil samples were collected from different land uses of on-going field experiments of ICAR Research Complex and also from traditional land use pattern representing Meghalaya. Physico-chemical and biological properties were analyzed in order to assess the carbon status and the potentiality to conserve carbon on long run. Available nitrogen content was recorded maximum in organically managed plot (NOC organic) both at surface and subsurface layers. Analysis of soil biological properties shows that Dehydrogenase activity is maximum in MZ ZT (maize plant under zero tillage) and minimum in Rice CT (Rice under conventional tillage) because of better environmental condition and proliferation of microbes due to adoption of conservation tillage. This data set will be utilized in calibration as well as in validation of carbon sequestration models.
- Land use changes such as change in forest cover due to deforestation, clearing of land for agriculture and human settlement has an adverse effect on environment which leads to changes in climate. The year 1991- 2001 shows that there was a declining trend of forest cover in the state of Meghalaya.

Project Directorate on Poultry, Hyderabad

- Impact of high ambient temperature on survivability of meat type (broiler), egg type (layer) and native (desi) type of chickens was investigated. The mortality due to heat stress was observed as the ambient temperature reaches 34°C. The mortality due to heat stress as the result of elevated ambient temperatures was significantly high in heavy meat type chickens (8.4%) as compared to light layer type (0.84%) and native type (0.32%) chickens.
- Feed consumption was decreased from 108.3 g/bird/day at the shed temperature of 31.6°C to 68.9 g/bird/day at 37.9°C. The egg production was significantly decreased both in layer and broiler breeders. The reduction was up to 7.5% in broiler breeders and 6.4% in commercial layers as compared to their standard egg production percentages.

- Effect of raise in shed temperature on body temperature and respiratory rate was recorded. The body temperature increased from 41°C at the shed temperature of 28°C to 45°C at 42°C of shed temperature. The critical body temperature at which the birds succumb to death was 45°C which was observed at the shed temperature of 42°C. The respiratory rate was increased from 46/min at 28°C to 150/min at 42°C. Emission levels of methane, nitrous oxide and ammonia were calculated based on the production of eggs and poultry meat in India. Indigenous technical knowledge practices relevant to climate change in poultry were documented.
- Various strategies to adapt poultry to climate change were identified. Suitability of naked neck chicken to elevated temperatures was validated. The experiments conducted during low and high ambient temperatures clearly suggest that naked neck birds performed significantly better than the normal birds with respect to thermo-tolerance, growth, feed efficiency and immunity in high temperatures as compared to normal broilers.
- Ambient temperature was observed to significantly influence various semen quality parameters in chicken. The sperm motility and fertilizing ability, live sperm counts were significantly reduced during high ambient temperature.

Tocklai Experimental Station, Tea Research Association, Jorhat

- Tea varieties responded positively to the metabolic activities of carbon assimilation with the increase of CO_2 concentration.
- Carbon assimilation increased linearly till it reached the level of 1150 ppm of CO_2 in the leaf vicinity. Transpiration losses almost remain unchanged with the increase of CO_2.
- The low value of rate constant and higher value of half life of decomposition of vermicompost and cattle manure in soil indicates its superiority to other manures in building up of soil organic carbon.
- Overall cup character (quality parameters) in terms of brightness, briskness, strength etc. of the made tea from organic treatment were superior to control (inorganic).

Anand Agricultural University, Anand

- The time series analysis of historical weather parameters of maximum and minimum temperature of data showed significantly increasing trend for winter (0.03°C/year), monsoon (0.016°C/year), post-monsoon (0.039°C/year) and annual (0.027°C/year). Rainfall trend for the same period was found non-significant.
- District wise average wheat productivity showed that Vadodara districts recorded the highest (2232 kg/ha) yield, whereas Ahmedabad recorded the lowest (1576 kg/ha) yield. The zone average yield was 2003 kg/ha. The average wheat productivity shows increasing trend.
- Panchmahal and Dahod district have higher area of Maize (each 20% of zone) as compared to rest of the districts. The average productivity of maize in the middle Gujarat Agro-climatic zone did not show any specific trend.

- Overall highest yield, biomass and LAI were recorded during projected period (2071-2100) by both the cultivars of wheat under late sowing (13th November).
- During the projected period of 2071 to 2100 there will be average 42, 26 and 27 % higher rainfall, maximum and minimum temperature respectively as compared to base line period.
- The cv. GW-322 of wheat crop performed better in early, late and very late sowing, whereas GW-496 performed better only up to late sowing during the projected period.

Directorate of Soybean Research, Indore

- Calibration and validation of InfoCrop model for Soybean and Groundnut has been completed. The model is able to simulate soybean and groundnut yield reasonably well and can now be used for various applications including climate change analysis.
- The assessment of climate change impact on soybean and groundnut has been completed and results show that the projected climate by the end of century under different future scenarios could result in increase in soybean yield ranging from 8-13% while change in groundnut yield range from -5 to +7% as compared to current yields.

Indian Institute of Sugarcane Research, Lucknow

- The annual average temperature reflected an increasing trend at Allahabad, Baharaich and Muzaffarnagar, a decreasing trend at Ballia, Fatehpur, Ghazipur, Hardoi, Lucknow and Varanasi and no trend at Banda, Gorakhpur and Lakhimpur-Khiri.
- The rainfall reflected a declining trend in all calendar months. During monsoon season, the highest rate of decline of 3.23 mm/year was noticed for the month of July and lowest rate of 0.55 mm/year in the month of June. The rate of decline of nearly 7.8 and 12.2 mm/year was noticed respectively for monsoon and annual rainfall.
- The CANEGROW (DSSAT model, ver 4.5) was calibrated for sugarcane varieties CoJ 64, CoLk 8102 for Lucknow conditions and CoSe92423 for Seorahi (Eastern UP) conditions from basic crop data available from literature.
- The basic information on crop parameters have been collected from experimental trials conducted at IISR, Lucknow and Genda Singh Sugarcane Research Institute, Seorahi (in eastern UP) for sugarcane varieties CoJ 64, CoLk 8102 and CoSe 82423. Some of the crop genetic coefficients for these varieties have been used in CANEGROW DSSAT model with encouraging results.

Punjab Agricultural University, Ludhiana

- The maximum temperature has decreased from the normal at Ballowal Saunkhri and Bathinda, however, for other locations no trend could be established. The annual and seasonal minimum temperature has increased over the past three decades at the rate of 0.07^{o}C/year at Ludhiana, 0.02^{o}C /year at Patiala, 0.03^{o}C/year at Bathinda. The analysis of past 108 years rainfall data at

Ludhiana revealed that the annual, *kharif* and summer season rainfall at Ludhiana has increased from the normal whereas the *rabi* and winter season rainfall at Ludhiana has either decreased slightly from the normal or not changed. The decrease in pan evaporation at Ludhiana especially in *kharif* season can be attributed to decreasing solar radiation trends.

- The InfoCrop model gave overestimation as well as underestimation of phenology, growth and yield of wheat cultivars under different environments. The anthesis and physiological maturity dates were simulated between -15 and +4 days and -13 to +14 days, respectively of the actual observed dates for wheat cultivars. The maximum LAI was and grain yield were simulated between -23 and +39% and -17 to +17% of the actual observed data for wheat cultivars under different environments. +17 % of the actual observed grain yield for October and November sown wheat crop. However, the model gave very low grain yield for wheat cultivars sown in December month.
- Special lectures on "Climate change and its effect on agriculture" were delivered by project team members at Krishi Vigyan Kendra's of the Punjab Agricultural University during "Farmer's Awareness Camp on Climate Change"
- A complete list of all the possible indicators pertaining to agriculture, climate, demographic characteristics, health and marketing which are expected to influence vulnerability of a region/ area has been prepared. The district-wise data on all these variables has been collected and the vulnerability indices are being constructed

CSK Himachal Pradesh Agriculture University, Palampur

- All the transplanting windows from 10th June to 10th July, the 20th June transplanting found to be the best transplanting window, which showed maximum rice yield followed by 30th June under Palampur conditions.
- Elevated carbon dioxide levels of 50 and 100 ppm over 370 ppm CO_2 level showed an increase of 7.6 to 11.7% and 14.8 to 20.8% in yield of rice in all the transplanting windows from 10th June to 10th July under Palampur conditions.
- Elevated temperature levels of 1^{o}C and 2^{o}C showed an increase in yield of rice in all the transplanting windows. The simulated yield with 1^{o}C and 2^{o}C rise in temperature showed increase of 6.8 to 25% and 14.8 to 35.6 percent under Palampur conditions.
- The temperature rise of 1^{o}C and 2^{o}C coupled with 50 ppm elevated carbon dioxide level caused reduction in the rice yield by 6.9 to 14.9% and 6.5 to 25.9% in all the transplanting windows from 10th June to 10th July. The further increase in carbon dioxide level to 100 ppm coupled with temperature rise of 1^{o}C showed increase in the yield to the tune of 3.3 to 9.5% in all the transplanting windows except 10th June transplanting whereas, with the rise of 2^{o}C temperature the 20th June and 10th July, transplanting showed increase in the yield by 0.3 to 2.1% in all transplanting windows under Palampur conditions.

- The reduction of 10 and 20% of rainfall under Palampur conditions caused slight reduction in the rice yield to the tune of 0.1 to 0.7% under 10% rainfall reduction except 30th June transplanting and 1.0 to 9.6% under 20% rainfall reduction.
- Under dry spell of first two weeks of August month the yield of rice crop reduced in first two transplanting windows 10th and 20th June by 31 percent whereas, There was a increase of 1 to 7 percent in yield under 30th June and 10th July transplanting windows. However, under rainfed conditions with the dry spell of first two weeks during the month of August and adaptation as one irrigation level the yield of rice showed increase of 42.8 to 46.5% in first two transplanting windows of 10th and 20th June whereas, the last two transplanting windows of 30th June and 10th July reduced the yield.
- The late sown wheat crop under irrigated conditions at Palampur indicated that 30th November sown to be the best planting window followed by 15th December under different planting windows from 30th November to 30th December.
- Elevated levels of carbon dioxide 50 ppm and 100 ppm simulated under irrigated conditions were compared with control 370 ppm indicated increase of 3.6 to 4.0% and 1.7 to 7.5% wheat yield in Palampur conditions under planting windows from 30th November to 30th December.
- Under irrigated conditions the increase in temperature of 1^{o}C and 2^{o}C also increased the yield in all the planting windows to the tune of 17.9 to 63.0% and 33.2 to 113.4%.
- The simulated yield of late sown wheat crop under irrigated conditions at Palampur increased with rise in 1^{o}C and 2^{o}C temperature when coupled with the elevated carbon dioxide levels of 50 and 100 ppm over different dates of sowing from 30th November to 30th December. The increase in the yield was found to be 23.0 to 69.7% and 39.5 to 123.5% under 1^{o}C and 2^{o}C elevated temperature levels when coupled with increased 50 ppm CO_2 level. Further increase of 100 ppm CO_2 level increased the yield by the tune of 27.9 to 76.1 percent.
- The simulated planting windows worked out from 20 years simulations for maize and mustard crop. The simulated planting windows and observed planting windows for maize and mustard crop in farmers' fields showed similar trends of yield in seven demonstrations during *kharif* 2009 and *rabi* 2009-10.
- The productivity and tea quality (Two leaf and bud) showed increasing trends in past 27 years in an experimental plot of 14 hectare area. The rainfall during March to May showed more than 50 percent reduction and reflected in significant reduction of tea yield and quality during these months. The further decrease of rainfall would decrease the yield and quality of tea. The Increase of temperature during June and July showed significant impact on tea quality and productivity. Tea being a shade loving plant showed increase in productivity with increase of sunshine during March to May but remaining month it showed decrease with increase of sunshine durations. Evaporation increase during April to July showed decrease in productivity. Relative humidity increase during March, August and September caused decrease in tea quality and productivity. The increasing trends of temperature and deceasing trends of rainfall at Palampur showed decrease of productivity and quality of tea.

- The trend analysis of river discharge or water inflow of Beas and Parvati in Beas basin and Sutlej in Sutlej basin showed significant decrease of water in flow in past 39 years database due to increase of temperature in the region.
- The local knowledge with respect to SW monsoon amount and distribution was validated with local observed data for different agro meteorological station. The local knowledge data showed compliance of local knowledge with observed weather data in past 36 years at Palampur whereas it showed inconsistent trends at Bajura and Dhaulakuan stations.
- In the climate literacy, three one day awareness programme / seminar on climate and weather and farmers were organized at CSKHPKV, Palampur, Rice and Wheat research station Malan and KVK Kullu where 152, 48 and 36 farmers participated in the seminar. The Hindi literature on climate and its impact and role of weather forecast in reducing the climate impact on crops were distributed**.**

Detailed Progress Report

INDIAN AGRICULTURAL RESEARCH INSTITUTE
NEW DELHI

Climate change impact, adaptation and net vulnerability assessment on crops

Simulation analysis was carried out on the impact of climate change on sorghum and maize crops in India, adaptation strategies and net vulnerability at regional level. The simulation analysis using InfoCrop model was carried out with inputs of the gridded weather data (IMD), soil data (NBSSLUP and ISRIC), climate change scenarios data from the PRECIS model, crop management and genetic coefficients for respective crop varieties.

The analysis was done for entire India. For this input data used were

1. Weather data: IMD 1^o x 1^o gridded data for baseline period (1969-1990)
2. Soil data rescaled to grid values from NBSSLUP and ISRIC soil data base
3. Crop Management: normal crop practices as followed by the farmers
4. Genetic coefficients of varieties best suitable for different regions
5. Climate change scenarios of MIROHR A1B, B1 and PRECIS A1b for 2030 and 2080 time periods; PRECIS A2 and B2 scenarios for 2080 time periods

Analysis on climate change impacts on production, adaptation options and gains and net vulnerability of irrigated maize and rainfed sorghum during *kharif* season are presented at all India level. Adaptation options include improved varieties (with duration changed by ± 10 days), increase in input efficiency (fertilizer and irrigation rescheduling) and providing additional nitrogen fertilizer amount.

Irrigated *kharif* maize

Analysis on the impact of climate change on irrigated *kharif* maize indicated reduction in maize yields by -6.83% in A1b 2030 scenario. This adverse effect of climate change on irrigated kharif maize production is projected to even higher in 2080 scenarios ranging from ~-14% in B2 scenario to about -25% in A1b and A2 scenarios (Fig.1). The negative impacts are more in states like Bihar, Chhattisgarh, Gujarat, Madhya Pradesh, Karnataka, Orissa, Tamil Nadu and Uttar Pradesh. These negative impacts ranged from about -8 to -20% in these states in A1b 2030 scenario while it ranged from -15 to -43% in A1b 2080 scenario. The impacts are almost similar in A2 2080 scenario but in B2 2080 scenario, impacts are less negative. The response of irrigated maize crop to climate change is more negative than either rice or wheat due to its limited response to higher CO_2, being a C4 crop.

In order to find the strategies to overcome or reduce these negative impacts, simulation analysis was done to quantify the adaptation capacity of irrigated kharif maize system in India. The negative impacts can be offset and even the production can be improved by about 13% by sowing improved variety in A1b 2030 scenario and by 6% in B2 2080 scenario. However, in A1b 2080 and A2 2080 scenarios, this adaptation option can only reduce the negative impacts of climate change leaving the irrigated *kharif* maize production vulnerable by about -2.5 to -5%. By sowing improved variety, the climate change impacts in states like Karnataka and Maharashtra can be overcome. However, to further reduce the climate change impacts, the improved variety needs to be managed with alerted input schedule (Table 9). By doing so, the net vulnerability in A1b and A2 2080 scenarios can be reduced and production in A1b 2030 and B2 2080 scenarios can be improved by 19.5% and 11.5%, respectively.

Managing the current variety or improved variety under improved input efficiency and additional fertilizer application are also assessed for adaptation capacity. Results indicate that managing the current variety under improved input efficiency and providing additional nitrogen can reduce the impacts but still leave the irrigated *kharif* maize production vulnerable by -1.82% in A1b 2030 scenario and by -10.6% in B2 2080 scenario. Gains due to this adaptation option are very less in A1b 2080 and A2 2080 scenarios. However, improved variety managed under improved input efficiency with additional nitrogen fertilizer can improve the production by about 24% in A1b 2030 scenario. This adaption option can almost offset the negative impacts of climate change in A1b 2080 scenario while can improve the yields marginally (3.5%) in A2 2080 scenario and substantially (~14.8%) in B2 2080 scenario.

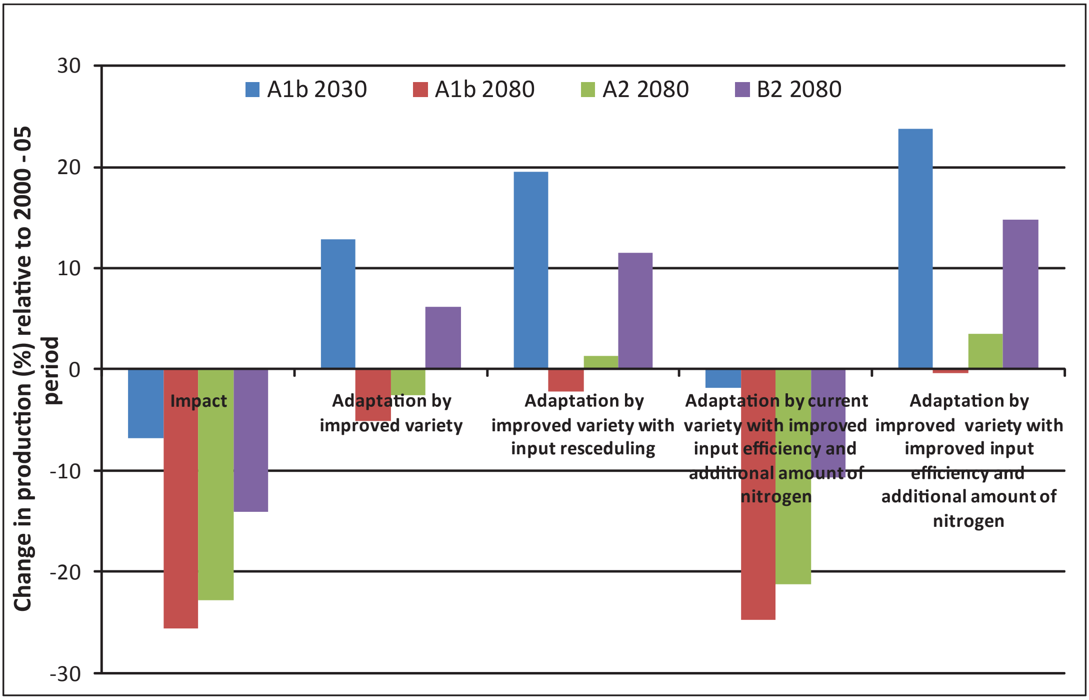


Fig.1. Impacts of climate change on irrigated maize during *kharif* season and net vulnerability after adaptation in different scenarios

Rainfed *Kharif* Sorghum

Analysis on the impact of climate change on rainfed *kharif* sorghum indicated that raifed sorghum production likely to benefit by about 2.5% in A1b and B2 scenarios of climate change while the positive impacts are projected to be even higher (~21.5%) in A2 2080 scenario at all India level (Fig.2). Rainfed *kharif* sorghum production in Maharashtra is projected to significantly benefit due to climate change. Parts of Gujarat, Andhra Pradesh, Tamil Nadu and Karnataka are also projected to benefit. On the other hand, the negative impacts are projected for states of Madhya Pradesh, Bihar, Orissa and Uttar Pradesh. These negative impacts ranged from about -1 to -5% in these states in A1b 2030 scenario while it ranged from -3 to -15% in A1b 2080 scenario.

Simulation analysis was done to quantify the adaptation capacity of rainfed *kharif* sorghum system in India for overcoming or reducing the negative impacts and to maximize the positive gains due to climate change. The negative impacts can be reduced by sowing improved variety in areas where negative impacts are projected. Improved variety can also improve the positive gains due to climate change. In case the current variety is managed with improved input efficiency and provided with additional nitrogen fertilizer, not only the negative impacts can be overcome but also can increase the rainfed *kharif* sorghum yields by 8.9% in A1b 2030, 4.47% in A1b 2080, 24.9% in A2 2080 and 6.31% in B2 2080 scenarios. In case improved variety is managed with improved input efficiency and provided with additional nitrogen fertilizers, the rainfed sorghum production can be increased in the range of 6 to 34% in different scenarios. With this adaptation strategy, the vulnerability of rainfed sorghum can be offset in states like Bihar, Chhattisgarh, Gujarat, Madhya Pradesh and Orissa. In spite all these adaptation strategies, some areas of Andhra Pradesh, Uttar Pradesh, Rajasthan and Karnataka are projected to still remain vulnerable.

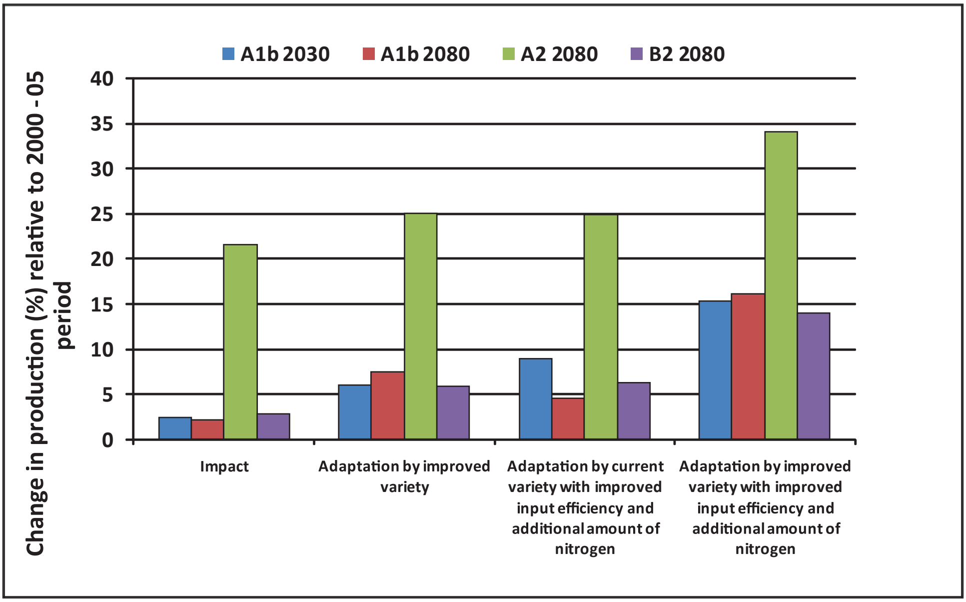


Fig.2. Impacts of climate change on rainfed sorghum during *kharif* season and net vulnerability after adaptation in different scenario

Emission of greenhouse gases from Indian agriculture

Assessment of greenhouse gas (GHG) inventory that identifies and quantifies a country's primary anthropogenic sources and sinks of GHG emission is central to any climate change study. India being a party to the United Nation's Framework Convention on Climate Change (UNFCCC) needs to develop, periodically update, publish and make available to the Conference of Parties, a national inventory of anthropogenic emissions by sources and removals by sinks of all GHGs. Accordingly the inventory of GHG emission by Indian agriculture was developed for the base year 2000 (Table 1).

Table 1. Greenhouse gas inventory for Indian agriculture for the year 2000

Source	CH_4 (Tg)	N_2O (Gg)	CO_2 eq. (Tg)
Ruminant	10.1	-	252.0
Rice cultivation	3.5	-	87.3
Manure management	0.1	0.1	2.5
Crop residue	0.2	4.0	4.9
Soil	-	132.3	39.4
Total	14.7	137.3	386.1

Tg = million ton, Gg = thousand ton

In 2000, Indian agriculture contributed 386.1 million ton (Tg) CO_2 eq. The agriculture sector primarily emitted CH_4 (14.7 Tg) and N_2O (137.3 thousand ton, Gg). The emission sources accounted for in the agriculture sector are enteric fermentation in livestock, manure management, rice cultivation, agricultural soils and burning of agricultural crop residue. The bulk of the GHG emission from the agriculture sector was from enteric fermentation (65%) followed by rice cultivation (23%) and the rest were contributed by manure management, burning of agriculture crop residue and application of N fertilizer to soil (Fig. 3).

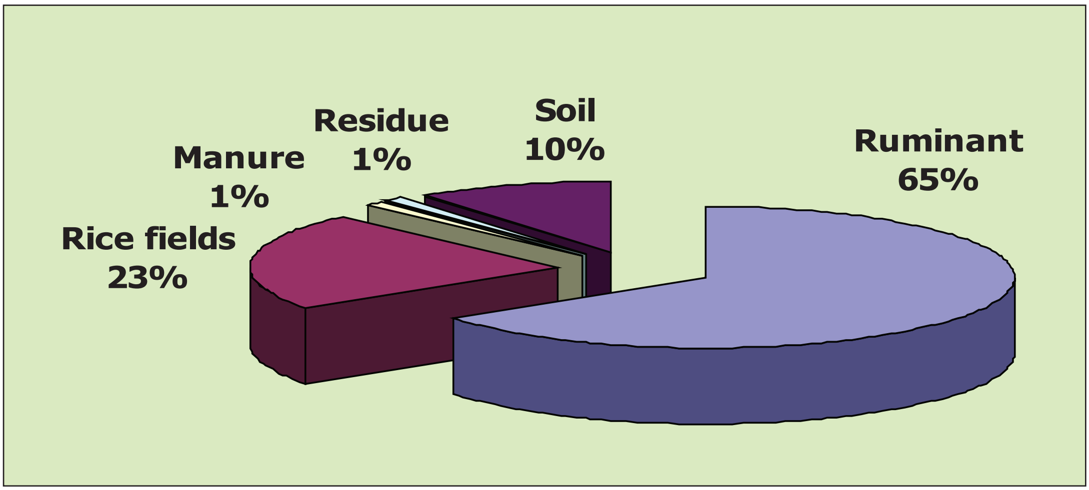


Fig. 3. Relative contribution of various sources to GHG emission in 2000

Methane emission

Livestock rearing, an integral part of Indian agriculture is the major contributor of methane. Although the livestock includes cattle, buffaloes, sheep, goat, pigs, horses, mules, donkeys, camels and poultry, the bovines and the small ruminants are the most dominant feature of Indian agrarian scenario, and the major source of methane emission. Methane emission due to enteric fermentation in 2000 was estimated to be 10.1 Tg. Buffalo and indigenous cattle, which are the main milk-producing animals in the country, contributed 44% and 42% total methane emission from livestock sector (Fig. 4). Cross bred cattle emitted 8% and the small ruminants emitted about 7% of methane.

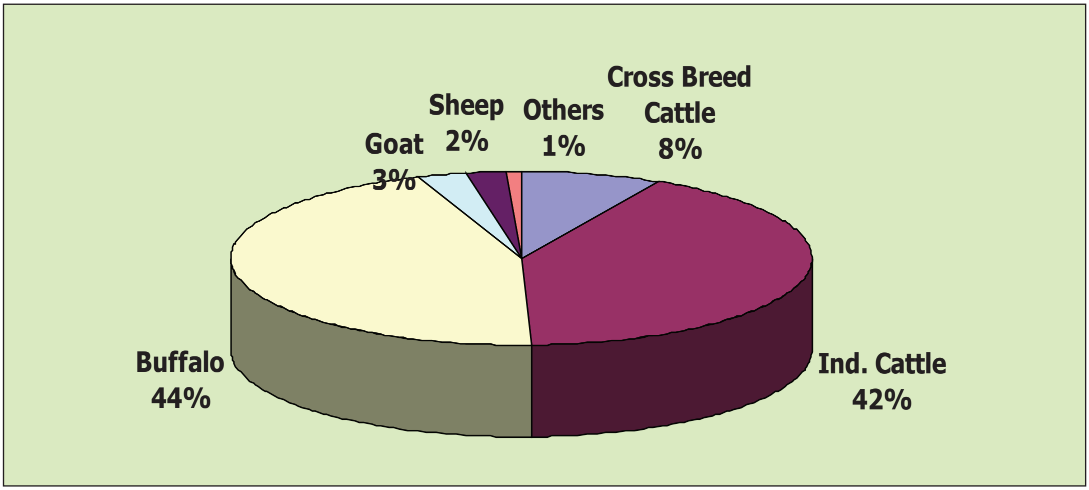


Fig. 4. Relative contribution of methane emission by different categories of ruminants

In India rice is cultivated under various water management conditions, depending on availability of water (Table 2). Methane emission due to rice cultivation was estimated to be 3.5 Tg. Continuously flooded rice emitted maximum methane (1111 Gg) followed by flood prone (827 Gg) and single aerated (598 Gg) rice cultivated areas.

Table 2. Area and methane emission in various rice-ecosystems in India

Ecosystem	Water regime	Area (M ha)	Emission (Gg)
Irrigated	Continuous flooded	6.85	1111
	Single aeration	9.08	598
	Multiple aeration	9.49	175
Rainfed	Drought prone	8.66	570
	Flood prone	4.35	827
Deep water		1.37	218
Upland		4.83	0
Total		44.62	3499

N_2O emission

During 2000, Indian agriculture produced 137.3 Gg of N_2O-N. Nitrogenous fertilizer application contributed 68% of that emission followed by manure and crop residue (Fig. 5). Because of increased use of N fertilizer, N_2O emission is also increasing over the years (Fig. 6).

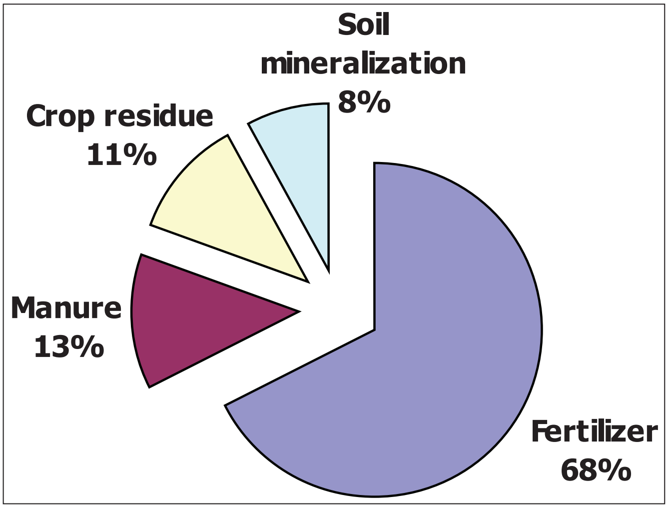


Fig. 5. Relative contribution of different sources to nitrous oxide emission

Though the inventory of GHG emission from Indian agriculture is fairly robust but it still suffers from various deficiencies like non-availability of country specific emission factors, lack of adequate monitoring stations and data quality. To capture the diverse soil and climatic conditions, different management practices and socio-economic status of the farmers influencing GHG emission, an appropriate national exercise is needed. This will not only improve estimates of emission and related impact assessments, but also provide a baseline from which future emission trajectories may be developed to identify and evaluate mitigation strategies.

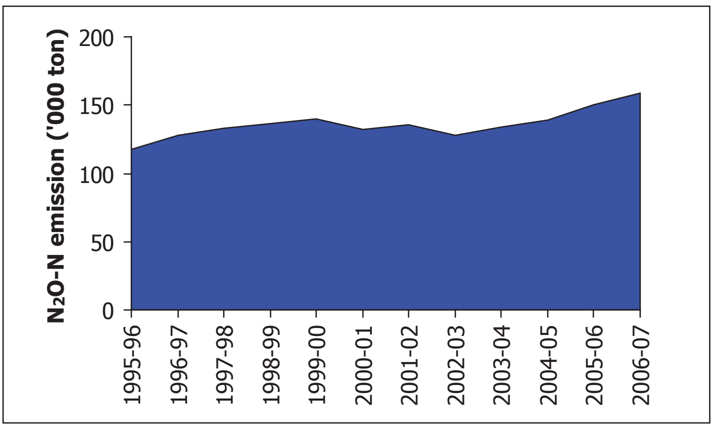


Fig. 6. Trend in nitrous oxide emission during 1995-2006

Objective: Assessing the impact of elevated temperature and CO_2 on growth, yield and quality and input resource utilization efficiency of rice, greengram, pigeonpea, wheat and chickpea using TGT and FACE and OTC facilities

Impact of elevated temperature on growth and yield of rice, groundnut and wheat

Three important field crops *viz.,* rice (*var.* Pusa 44) and groundnut (*var.* B95) during *kharif* and wheat during *rabi* season were grown in temperature gradient tunnel (TGT) at varying thermal regimes (+0.8 to 3.5°C) with low, medium and high nitrogen levels to assess the growth, physiological, yield and quality response of these crops to rising atmospheric temperature at varying fertility levels. Rise in temperature hastened flowering in rice and groundnut crops. Elevated temperature also caused marked reduction in biomass and yield of rice and wheat crops under low, medium and high fertility levels, which was mainly due to reduction in grains/panicle followed by panicles / pot (Fig.7 & 8). Grain yield showed greater thermal sensitivity as compared to biomass under all fertility levels. In general plants grown under low fertility level showed higher thermal sensitivity compared to medium and high levels. Groundnut showed marked reduction in biomass and seed yield under elevated temperature mainly due to substantial reduction in the number of nut m^{-2} and 1000 seed weight (Fig. 9).

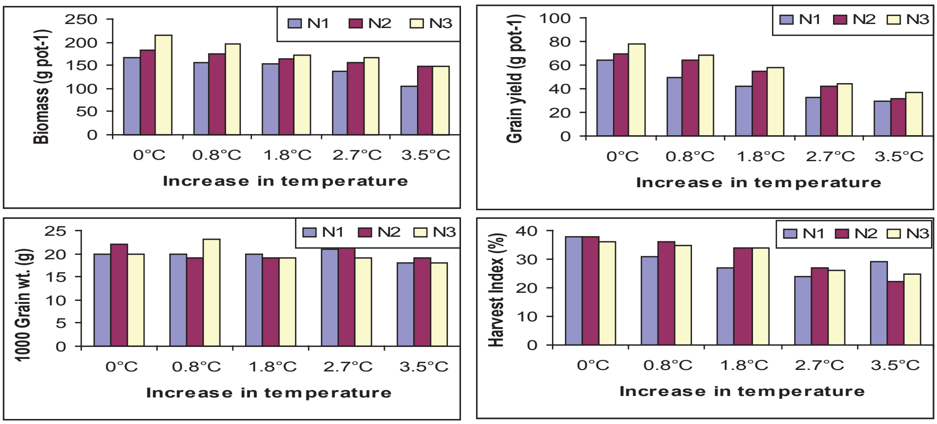


Fig. 7 Effect of elevated temperature on yield attributes of rice crop

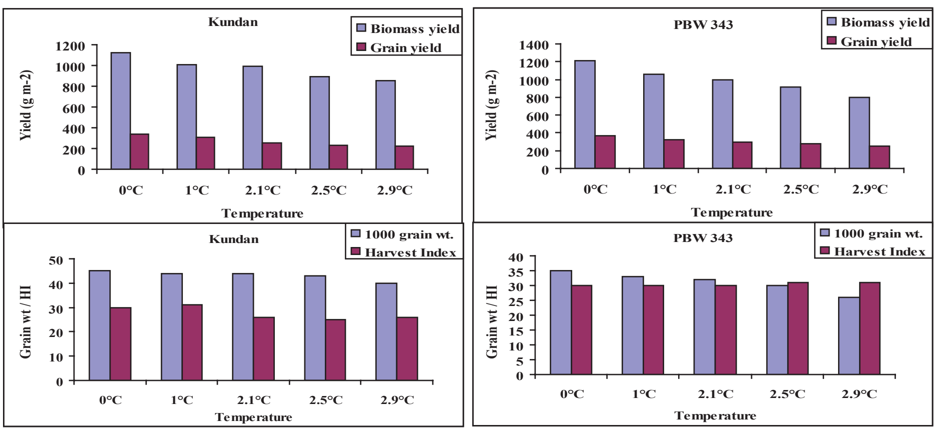


Fig. 8 Effect of elevated temperature on biomass and grain yield of wheat crop

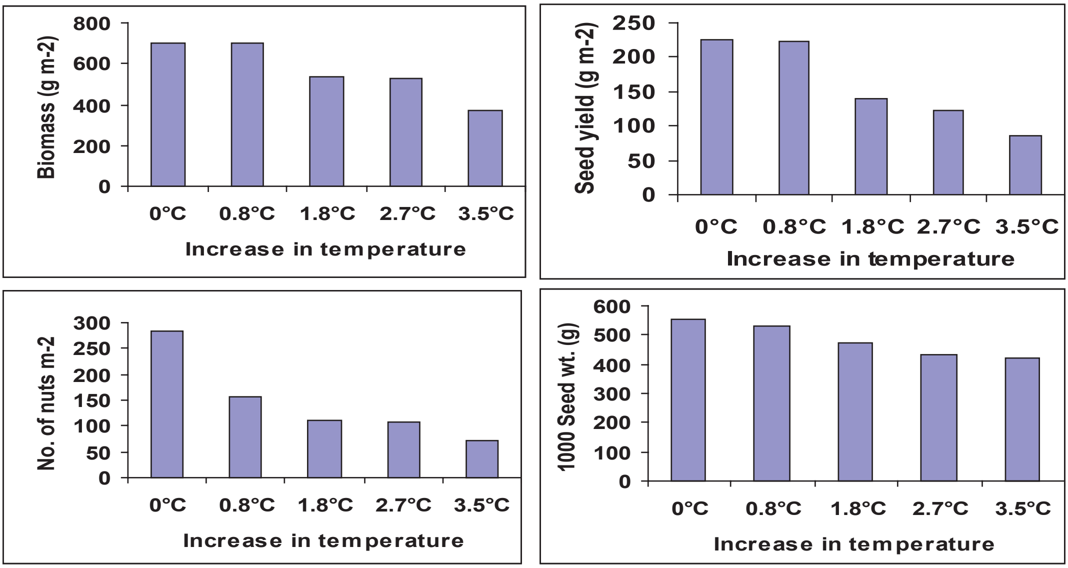


Fig. 9 Effect of elevated temperature on yield attributes of groundnut crop

Impact of high temperature during different growth phases on growth and yield of groundnut

Groundnut crop was subjected to elevated temperature during germination to flowering (G-F), flowering to maturity (F-M) and germination to maturity (G-M) to assess the impact of high temperature during different growth phases of crops on their growth and productivity. Groundnut showed greater thermal sensitivity during reproductive growth phase followed by vegetative growth phase. However, crop subjected to entire growth phase showed additive detrimental effect of high temperature during vegetative and reproductive growth phases. Reduction in yield was attributed to marked decline in nuts m^{-2}, 1000 seed weight and biomass (Fig.10).

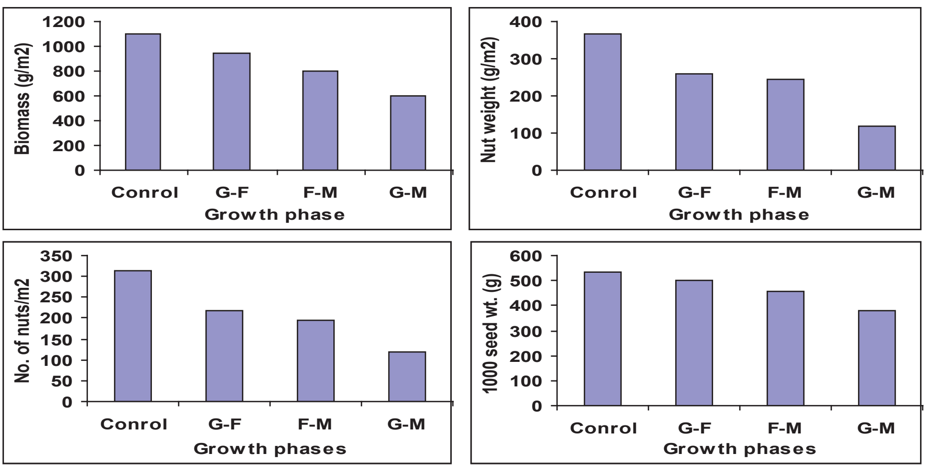


Fig. 10. Impact of high temperature on groundnut crop at different growth stages

Impact of elevated CO_2 on growth and yield of rice, wheat and groundnut

Three important field crops viz., rice (var. Pusa 44) and groundnut (var. B95) during *kharif* and wheat (var. PBW 343) during *rabi* were grown in FACE (560 ppm CO_2) at low, medium and high nitrogen levels to assess the growth, physiological, yield and quality response of these crops to elevated CO_2 level. Contrary to increased temperature, elevated CO_2 level in the air enhanced the biomass and seed yield of rice and wheat at all fertility levels but the CO_2 fertilization effect was greater on grain yield as compared to biomass especially at higher fertility level. Enhancement in yield was attributed to marked increase in leaf area/plant, panicles/pot, grains/panicle and biomass (Fig.11). Photosynthesis rate was higher in rice crops grown inside the FACE ring irrespective of N levels. At 65 days after sowing (DAS) photosynthesis rate was 20.8 µmol m^{-2} s^{-1} in high nitrogen (HN) treatment inside the FACE ring, while at same stage in control plots photosynthesis rate was much less (14.6 µmol m^{-2} s^{-1}) in high nitrogen treatment.

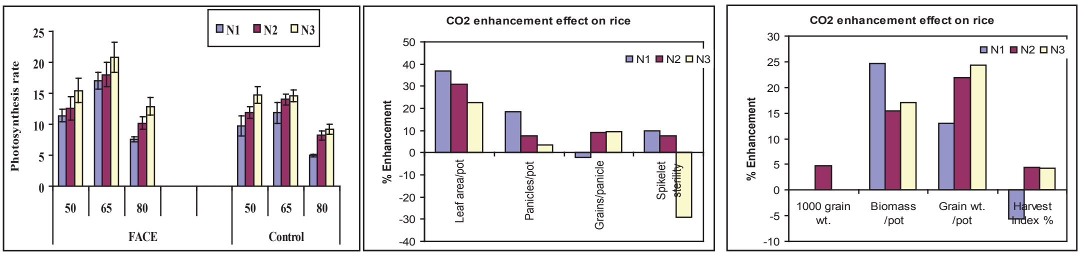


Fig.11. Impact of high CO_2 on photosynthesis and yield of rice

Groundnut crop exposed to high CO_2 condition showed higher photosynthesis rate and high leaf area index (LAI). Throughout the crop growth season, LAI was found to be higher in crops grown in elevated CO_2 condition. Maximum photosynthesis rate of groundnut crop was recorded as 21.1 µmol m^{-2} s^{-1} in elevated CO_2 condition, while it was 18.4 µmol m^{-2} s^{-1} in normal crop (Fig. 12). Elevated CO_2 enhanced the biomass and seed yield of groundnut, which was mainly attributed to marked increase in biomass and nuts m^{-2}.

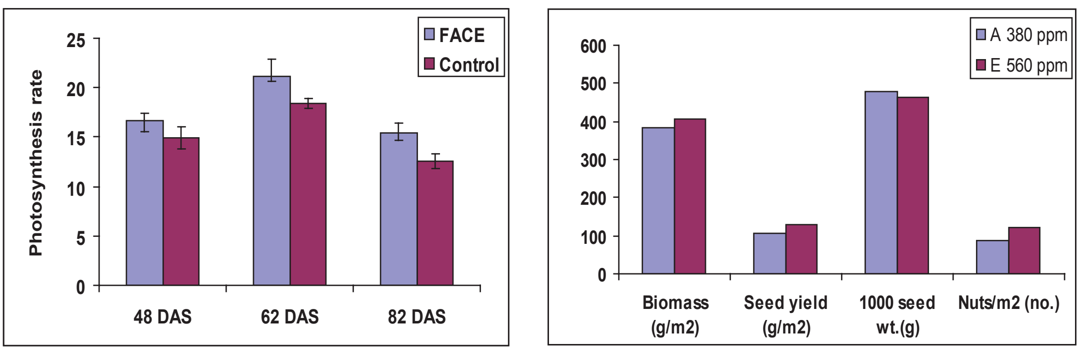


Fig.12. Impact of high CO_2 on photosynthetic rate (µ mol $m^{-2}s^{-1}$) and yield of groundnut

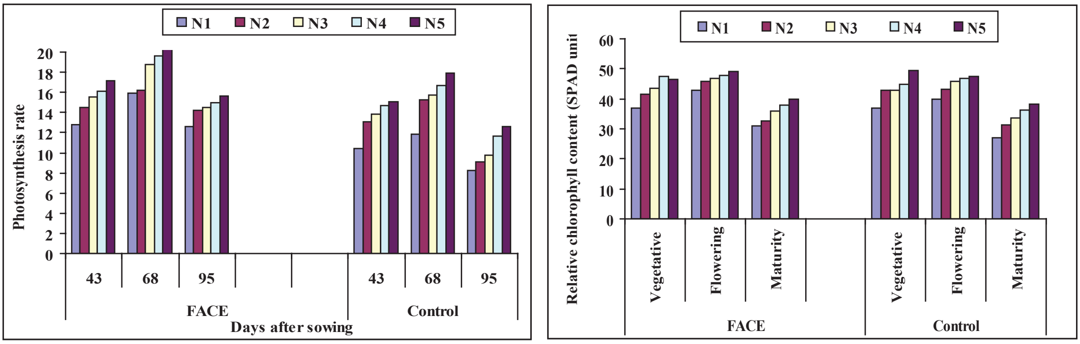


Fig.13. Impact of elevated CO_2 on photosynthesis rate (μ mol $m^{-2}s^{-1}$) and chlorophyll content in wheat crop

Inside the FACE rings wheat crop (*var.* PBW 343) was grown with 5 nitrogen (N) levels (N1= 0, N2=1, N3=2, N4=3 & N5=4 gm N pot^{-1}) during the *rabi* season and exposed to elevated CO_2 (580 ppm) level throughout the crop growing period. This has resulted in higher photosynthesis rate, more chlorophyll content in leaves, which was reflected ultimately in higher growth and yield of crop. Photosynthesis rate in all N levels was higher in crops exposed to high CO_2 level. Relative chlorophyll content was also more in crops grown inside FACE ring at all growth stages (vegetative, flowering & maturity) (Fig. 13). Biomass and grain yield of wheat was higher in elevated CO_2 treatment at all N levels (Fig.14). At low N levels (0 & 1 gm N pot^{-1}) 1000 grain weight of wheat increased at elevated CO_2, but at higher N dose, it was less under high CO_2 level. Although crop yield increased with CO_2 exposure, but harvest index of wheat crop either decreased or remained same at different N levels in high CO_2 treatment (Fig.15). This proves that enrichment of CO_2 caused more increase in biomass yield than that of grain yield. At elevated CO_2 condition protein content in rice grains decreased at all 3 nitrogen levels. Reduction in protein content was maximum (21.4%) in high N treatment (Fig. 16).

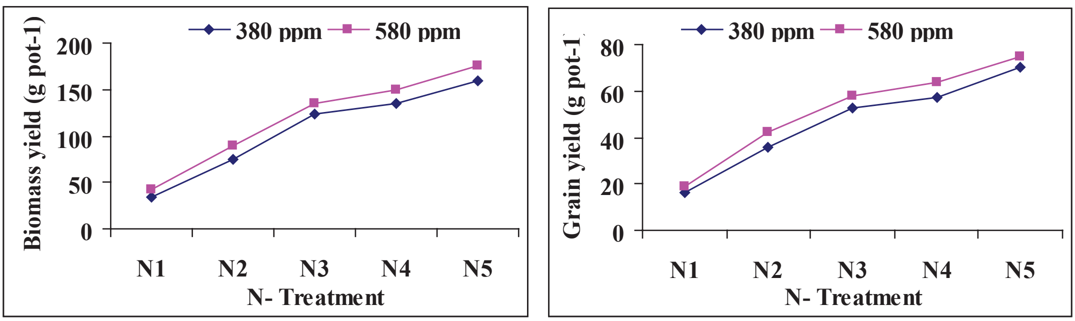


Fig.14. Effect of elevated CO_2 on yield of wheat crop

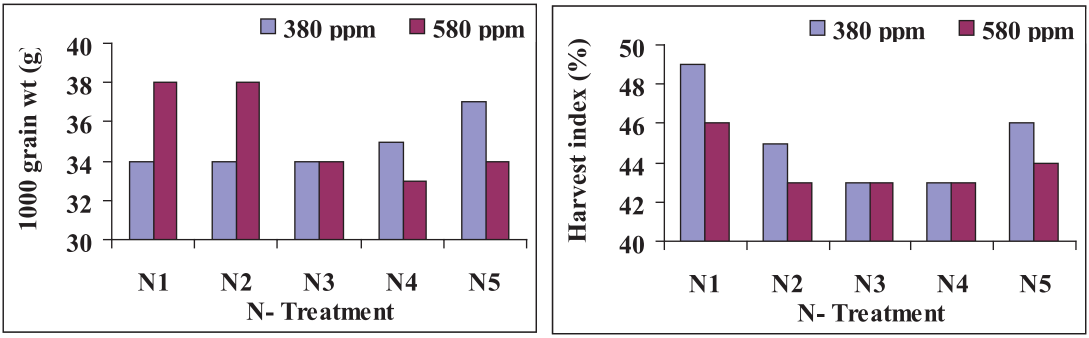


Fig.15. Effect of elevated CO_2 on 1000 grain wt.(g) & harvest index (%) of wheat crop

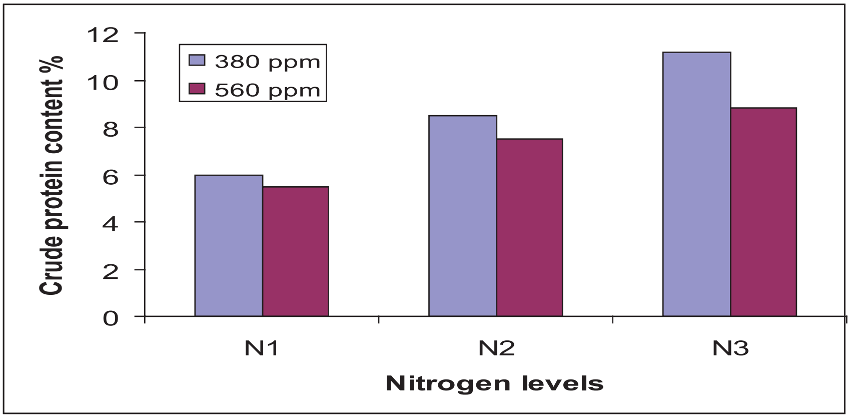


Fig.16. Impact of high CO_2 on photosynthesis and protein content in rice grainop

Effect of high CO_2 and temperature on water relations, antioxidant enzymes and grain quality traits of rice and its parental lines

An experiment was conducted in open top chambers (OTCs) at IARI farm to evaluate the impact of elevated CO_2 and temperature on hybrid aromatic PRH 10 and its parental rice genotypes PRR 78 (male parent) and PUSA 6B (female parent). Plants were raised in normal soil in large drums of 18″ diameter inside OTCs maintained with normal (380 µmol mol^{-1}) and elevated levels (600 µmol mol^{-1}) of CO_2. There were four replicate drums per genotype and treatment and two OTC chambers. At panicle initiation stage (50-55 days after transplanting) and anthesis stage (90-95 days after transplanting), some plants were exposed to elevated temperature of about 3° C above ambient for 10 days. After high temperature treatment the pots were shifted back to OTCs. Antioxidant enzymes (Asc. POX, POX, CAT and SOD) activity was measured in the leaves of the plants after treatment at both the stages. The activity increased in all the genotypes under high temperature with PRH 10 and PUSA 6B showing similar trend at PI stage. On the other hand, PRR 78 showed increased activity at anthesis stage (Fig.17). Enhanced enzyme activity under temperature stress could help in scavenging the free radicals produced under high temperature. Temperature effect was not evident in water relations in hybrid and parental lines as a temperature increase of 3°C was not critical to cause associated changes. Relative water content was maintained in the hybrid PRH 10 and the parents P6B and PRR 78 after high temperature exposure at both the sampling times. RWC stayed over 90% even in leaves of plants exposed to increased temperature of 3°C. Water potential trend paralleled that of relative water content and values were maintained in the range of -1.6 to -2.2 MPa regardless of the temperature. Leaf osmotic potential was not affected at both stages of sampling. Turgor potential was low under high temperature given at panicle initiation stage compared to ambient conditions (Table 3). The small effect observed in terms reduction in turgor potential under high temperature reflected significant tolerance to the increased temperature as relative water content was maintained. This may have been due to the well-watered conditions maintained throughout the growth period. At maturity, plants were harvested and the grains were subjected to various quality analysis. Test weight of grain increased under elevated CO_2 in the hybrid and female parent and was unchanged in male parent. Proportion of high density grains also enhanced in CO_2 enriched plants of all genotypes (Table 4). Increased grain yield observed under elevated CO_2 was due to both increased tiller number /plant and due to bolder and denser grains in these genotypes. Most important quality parameters for basmati rice are the slenderness of the grain, elongation of the grain after cooking and aroma of cooked rice. The length/breadth ratio was not affected by the treatments, but the elongation ratio of the cooked grain improved in the female parent Pusa 6B, declined in the male parent PRR 78 and was unchanged in the hybrid PRH 10. Aroma declined in the grain harvested from plants of all the genotypes exposed to higher levels of CO_2. Alkali spreading value in the hybrid and female parent Pusa 6B decreased and hence the gelatinization temperature increased and the cooked rice became firmer when the plants were exposed to elevated CO_2. Amylose content increased marginally and protein, iron and zinc contents decreased significantly (Table 5 & 6). Germination characteristics like percent germination, seedling vigour as determined by seedling length and seedling weight showed marginal increase in all genotypes due to elevated CO_2 concentration. It may be concluded that elevated temperature affected the genotypes by upregulating the antioxidant defense system with insignificant change in plant water relations. High temperature did not affect grain quality but high CO_2 affected head recovery, test weight, proportion of high density grains and germination characteristics, but adversely affected traits like aroma, gelatinization temperature and micronutrient contents.

Table 3. Impact of high temperature at panicle initiation (PI) and anthesis stage on leaf water characters

	PRH 10				Pusa 6B				PRR78			
	PI		Anthesis		PI		Anthesis		PI		Anthesis	
	Ambient	High	Ambient	High	Ambient	High	Ambient	High	Ambient	High	Ambient	High
RWC (%)	89.8	92.4	89.4	91.8	91.5	90.5	88	87	90.2	89	94.7	91.6
Water potential (-MPa)	2.092	2.256	1.878	1.933	1.743	1.853	1.907	1.824	1.796	1.623	1.723	1.693
Osmotic potential (-MPa)	2.735	2.736	2.152	2.168	2.667	2.506	2.735	2.666	2.23	1.861	2.666	2.551
Turgor potential (MPa)	0.643	0.480	0.274	0.235	0.924	0.653	0.828	0.842	0.434	0.238	0.943	0.858

Table 4. Impact of elevated CO_2 on yield and grain quality traits of rice hybrid and its parents

Trait	PRH-10		PRR 78		Pusa 6B		CD at 5%
	Ambient	Elevated	Ambient	Elevated	Ambient	Elevated	
Biomass/ plant (g)	148.2	181.8	151.5	161.8	145.2	160.9	6.06
Grain yield/plt. (g)	90.73	105.9	79.6	82.5	85.7	96.1	4.25
Head recovery %	56.8	63.1	63.4	64.1	62.5	64.1	2.53
1000 grain wt. (g)	20.0	21.7	15.9	15.9	21.7	24.1	0.62
Proportion of high density grains	0.60	0.79	0.12	0.19	0.53	0.86	0.057

Table 5. Impact of elevated CO_2 on cooking quality traits of rice hybrid and its parents

Trait	PRH-10		PRR 78		Pusa 6B		CD at 5%
	Ambient	Elevated	Ambient	Elevated	Ambient	Elevated	
L/B ratio	4.30	4.33	4.04	4.03	4.58	4.61	0.058
Elongation ratio	1.74	1.74	1.63	1.48	1.59	1.74	0.040
Alkali spreading value	5.58	5.33	2.67	3.37	5.0	4.3	0.47
Aroma	0.75	0.62	1.22	1.25	0.96	0.82	0.14
Amylose %	20.0	21.0	15.7	15.8	22.6	22.7	0.38

Table. 6. Impact of elevated CO_2 on nutrient and seed quality of rice hybrid and its parents

Trait	PRH-10		PRR 78		Pusa 6B		CD at 5%
	Ambient	Elevated	Ambient	Elevated	Ambient	Elevated	
Fe ppm	0.837	0.797	1.294	0.912	1.84	1.657	0.24
Zn ppm	0.527	0.328	0.397	0.373	0.506	0.485	0.057
Germination (%)	98.3	98.5	95.5	96.2	95.2	97.4	1.99
Seedling length (cm)	34.8	36.1	29.1	30.0	34.0	34.5	0.58
Seedling dry wt. (mg)	93.5	98.2	73.6	73.8	95.8	98.1	3.22

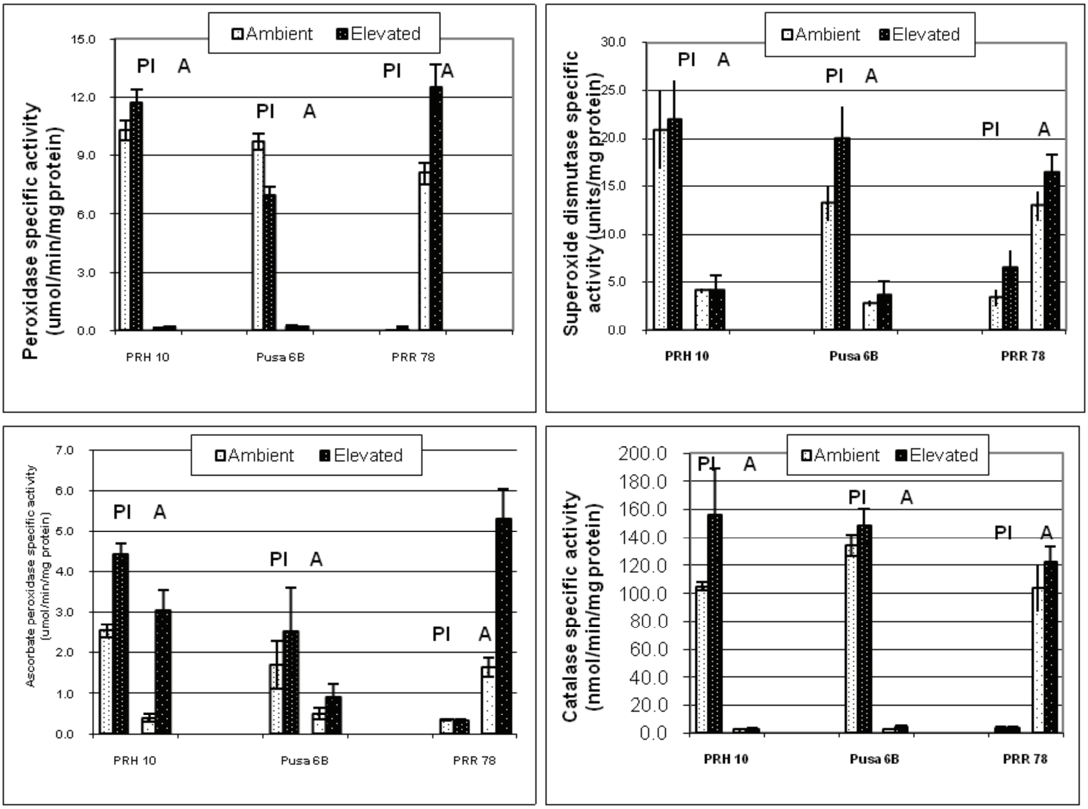


Fig.17. Effect of high temperature at panicle initiation (PI) and anthesis (A) stage on ascorbate peroxidise, catalase, total peroxidise and superoxide dismutase activity in rice hybrid and parental lines

Impact of elevated CO_2 on radiation interception, plant and soil biophysical properties in pigeon pea (*Cajanus cajan* L.)

An experiment was conducted at IARI, New Delhi in open top chambers where two genotypes of pigeon pea (Pusa 992, medium maturity, indeterminate type; P 2009-5/4, an advance material that is determinate type) were exposed to elevated levels of CO_2 (600 ppm) and its performance was compared with that grown in similar OTC under ambient CO_2 levels (370 ppm). Interception of photosynthetically active radiation (PAR), leaf temperature, transpiration, stomatal resistance, canopy temperature and leaf area index (LAI) were measured during the growth period. At harvest, yield components were recorded. From the top soil of the rhizosphere, active and labile carbon pool was estimated at harvest and compared to initial values.

The relationship between fraction of the PAR intercepted and LAI was fitted into Beer-Lamberts formula and the extinction coefficients k were calculated. The values of k were less (0.874 and 0.749) for plants under elevated CO_2 compared to ambient conditions (0.986 and 0.942) for Pusa 992 and PS 2009 respectively. This indicated that the plants under elevated CO_2 have more erected leaves and that the light was more effectively scattered down into the leaf canopy. Radiation use efficiency (RUE) calculated as the slope of the regression of accumulated biomass on cumulative intercepted radiation was significantly greater for plants grown under elevated CO_2 conditions (1.402 and 1.426) than for those grown under ambient levels of CO_2 (1.179 and 1.293) (Fig.18). These results are important to crop modellers who simulate growth under future scenario of elevated CO_2 levels.

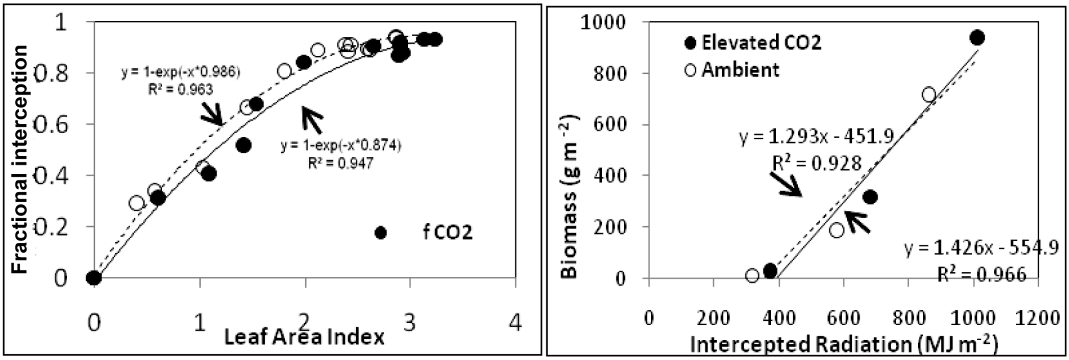


Fig.18. Relationship between fractional radiation interception and LAI & between above - ground biomass and cumulative intercepted solar radiation for cv. Pusa 992

During the crop growth period, there was no feed- back and closure of stomata and the stomatal resistance was lower and hence the transpiration rate was higher in CO_2 enriched plants of pigeon pea (Fig.19). Development of LAI was significantly higher in these plants due to which there was mutual shading and the canopy was kept cooler compared to control plants (Fig. 20). Until 80 days after sowing, due to water stress, the canopy temperatures were more than the air. But with subsequent rain, the canopy became cooler, the difference between canopy and air temperature was more negative in CO_2 enriched plants than that of control.

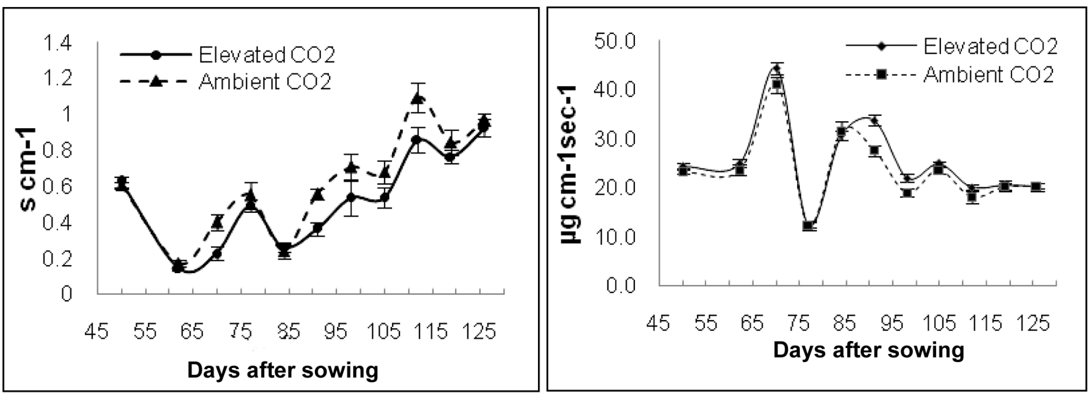


Fig.19. Seasonal variation in leaf stomatal resistance and transpiration rate under elevated and ambient CO_2 levels in Cv. Pusa 992

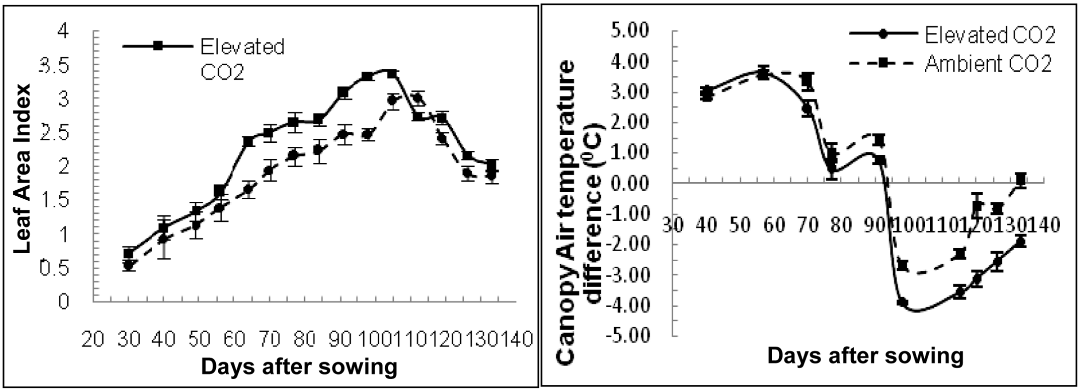


Fig.20. Seasonal variation in leaf area index and canopy-air temperature difference under elevated and ambient CO_2 levels in Cv. Pusa 992

At harvest, the yield components showed that in Pusa 992, due to elevated CO_2, biomass in terms of leaf, stem and pod weight increased significantly but the increase in grain weight was only 12% over the control plants (Fig.21). In PS 2009, the plants under elevated CO_2 did not mature and remained green and the seeds were not fully developed when the experiment was terminated at 145 days after sowing. However, biomass increased in different plant parts except grain weight.

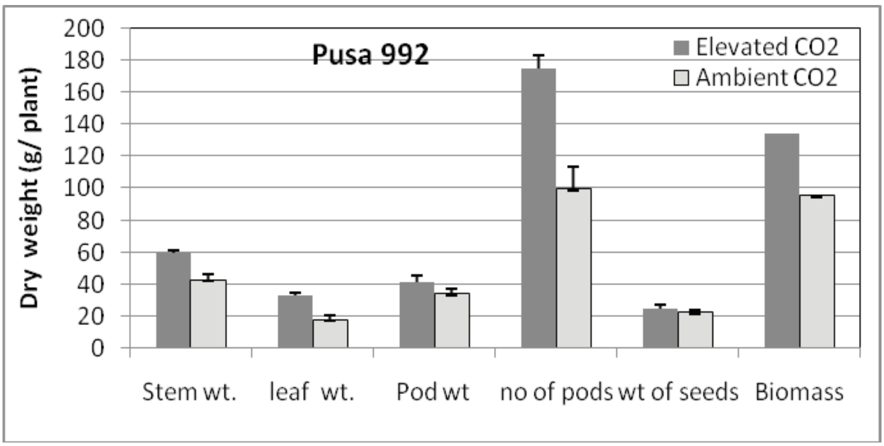


Fig.21. Dry weights of different plant components at harvest under elevated and ambient CO_2 levels in cv. Pusa 992

The top soil after the harvest near the root zone of the crop showed that all the different fractions of soil carbon increased over the initial values in both elevated and ambient CO_2 conditions (Fig.22). However among the treatments, the increase was significantly greater for elevated CO_2 over the ambient controls. Since active and labile carbon–pools serves as a clue to soil organic carbon dynamics and that all C-pools recorded a significant increase over the initial status, this may impact short to medium term effect on soil carbon sequestration.

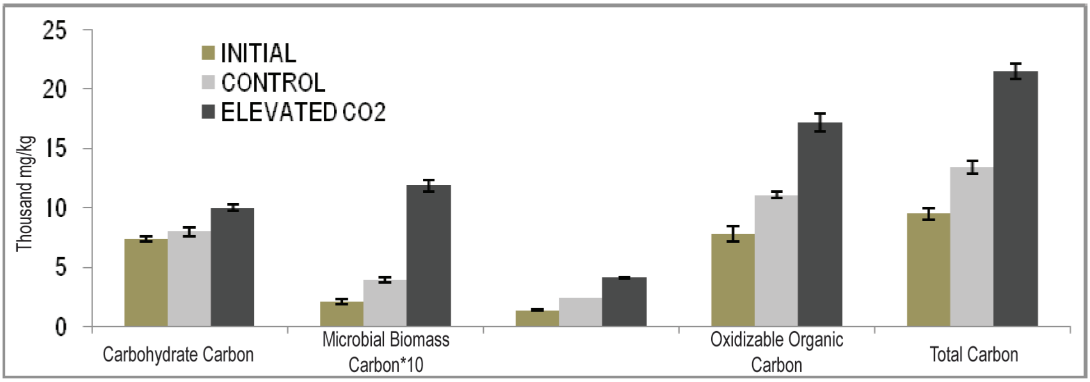


Fig.22. Active carbon pools in pigeon pea rhizosphere at harvest as influenced by elevated and ambient CO_2 levels

Effect of high temperature on reproductive development and yield of chickpea genotypes (*Cicer arietinum*)

An experiment was designed to observe the effect of high temperature on the reproductive physiology, growth dynamics and yield of two promising chickpea (*Cicer arietinum* L.) genotypes namely Pusa 1103 and Pusa 1105. For high temperature treatment plants were raised inside the poly tunnel where the temperature exceeded 3 to 4° C higher than ambient. Both chickpea genotypes were sown on the same date on 10-11-2009 at ambient and elevated temperature and all other conditions were maintained similar except high temperature taken as a treatment. Observations were taken starting from the flower initiation to physiological maturity of the both genotypes. Final yield was calculated after harvesting of plants.

A considerable variation was observed on the total flowers produced and the difference was apparent both at treatment and genotypic level. Total number of flowers in Pusa 1103 was found to decrease by 14.26 per cent, while the same was increased in Pusa 1105 by 5.25 per cent under high temperature condition (Fig. 23). The more pronounced effect was observed on the flowering initiation and flowering pattern of both genotypes. At ambient temperature flower initiation was observed at 92 days after sowing in both genotypes while it was observed at 50 days after sowing under high temperature i.e. significantly earlier (42 days) than ambient temperature (Fig. 24). Though, initial response of flowering was better in Pusa 1105, but Pusa 1103 showed overall better response at the peak of flowering in both ambient and high temperature conditions. Variation was also significant for total flowering period as it was found 36 days under high temperature in comparison to 24 days under ambient conditions. Similarly pod initiation was observed 10 days earlier in both genotypes under high temperature, which started at 65 days after sowing in comparison to ambient condition where it started at 75 days after sowing for both the genotypes. In addition to the effect of high temperature on pod initiation, the duration of pod development extended up to 24 days under high temperature in comparison to 18 days under ambient condition (Fig. 25). Total number of pods produced was found to decrease in both genotypes under high temperature by 22.78 per cent (Pusa 1103) and 21.32 per cent (Pusa 1105). However, difference in total number of pods produced was considerable in both genotypes as 94.1, 65.66 under ambient temperature and 72.66, 51.66 under high temperature in Pusa 1103 and Pusa 1105 respectively. Significant effect of high temperature was observed on flower abortion ratio in both genotypes. Under the ambient condition, significant genotypic variation was observed and Pusa 1105 showed higher flower abortion ratio (52.74%) in comparison to Pusa 1103 (41.26%). This pattern was obviously increased under high temperature and flower abortion ratio obtained as 64.26 per cent for Pusa 1105 and 47.79 per cent for Pusa 1103 respectively (Fig.26). Effect of high temperature was also determined on pod growth rate in both chick pea genotypes. Though both genotypes followed almost similar kinetics of growth by gain in dry weight in unit time, the duration of pod development was found 30 days under high temperature in comparison to 24 days under ambient temperature. Moreover the maximum gain in dry weight of pod was decreased in both genotypes by 25.60 per cent in Pusa 1105 and 13.77 per cent in Pusa 1103 under high temperature respectively (Fig.27).

The overall effect of high temperature on yield components like total biomass/plant, pods weight/plant and seeds weight/plant were observed and all three components showed considerable reduction under high temperature treatment (Table.7). It was observed that under the high temperature Pusa 1103 showed less reduction in total plant biomass, pod dry weight and seed weight in comparison to Pusa 1105. In contrast to reduction in all yield attributes, total biomass in Pusa 1105 was slightly increased by (0.51%) under high temperature.

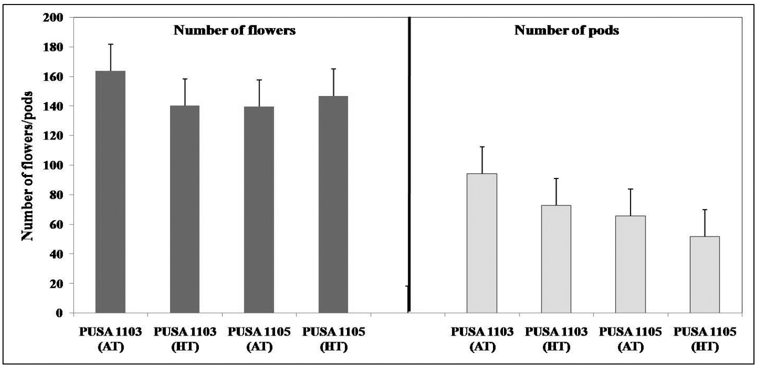
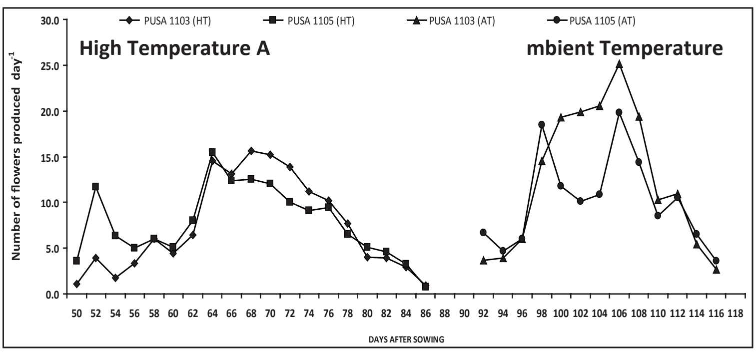
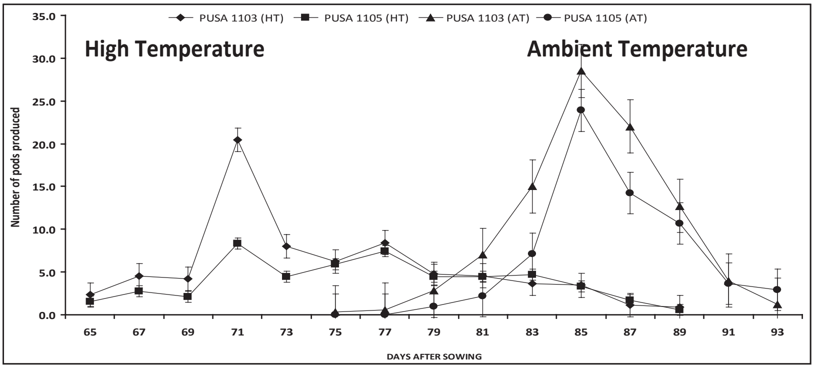


Fig.23. Effect of high temprature on total number of flowers produced and total number of pod produced in two chickpea genotypes PUSA 1103(Desi) and PUSA 1105 (Kabuli)



Observations were taken in alternate days starting with the day of flower initiation.

Fig.24. Effect of high temprature on number of flowers produced on the day in two chickpea genotypes PUSA 1103(Desi) and PUSA 1105 (Kabuli)



Observations were taken in two days interval starting with the day of pod initiation.

Fig.25. Effect of high temprature on number of pods produced on the day in two chickpea genotypes PUSA 1103(Desi) and PUSA 1105 (Kabuli).

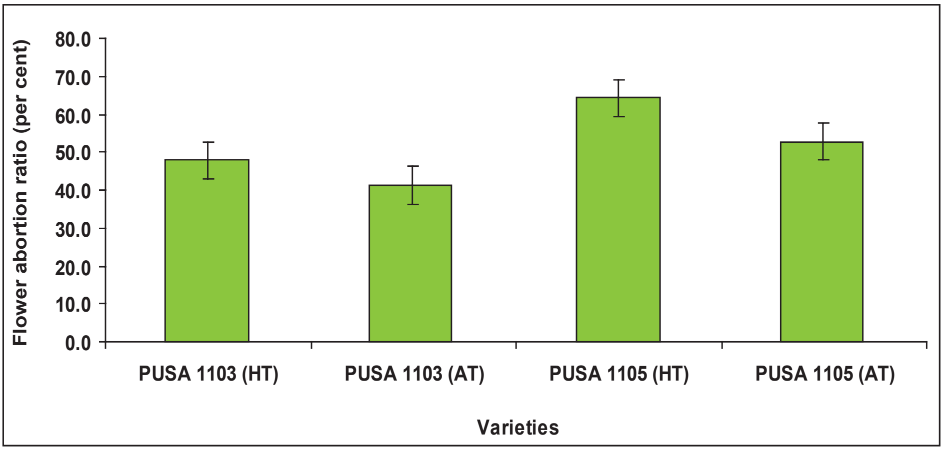
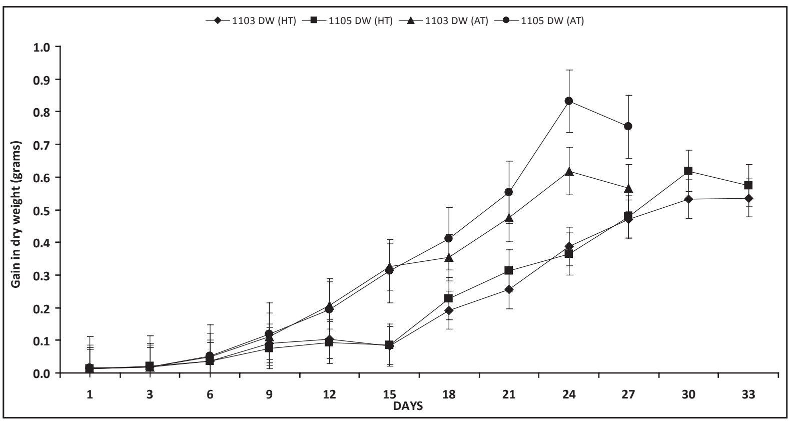


Fig.26. Effect of high temprature on flower abortion ratio in two chickpea genotypes PUSA 1103(Desi) and PUSA 1105 (Kabuli)



Pod samples were taken in two days interval starting with the day of pod initiation.

Fig.27. Effect of high temprature on pod growth rate of two chickpea genotypes PUSA 1103(Desi) and PUSA 1105 (Kabuli)

Table 7. Effect of high temprature on total biomass, pod weight and seed weight in two chickpea genotypes PUSA 1103(Desi) and PUSA 1105 (Kabuli). Mean values shown in the data represents average of nine observations

Genotype	Total Biomass/Plant	Pods weight/Plant	Seed Weight/Plant
PUSA 1103 (AT)	50.313	27.722	24.255
PUSA 1103 (HT)	37.048	20.968	19.015
Per cent change	-26.36	-24.36	-21.60
PUSA 1105 (AT)	34.035	21.977	16.747
PUSA 1105 (HT)	34.210	13.913	10.208
Per cent change	+0.51	-36.69	-39.04

Objective: Adaptation strategies to minimize the climatic risk in different crops through crop / varietal selection, fertilization, irrigation and planting scheduling etc.

In order to cope with global warming effect on crop productivity, some agronomical adaptation measures such as varying N levels, dates of sowing and varietal evaluation were undertaken in wheat and rice crops. The results pretaning to response of crops to different nitrogen levels under elevated CO_2 and temperature are presented above.

In this experiment, four medium duration varities, one long duration variety and one short duration variety were sown on 1st, 15th and 31st December. Results indicate delay in sowing, cause differential reduction in yield among the varieties of different duration. In late sown conditions, short duration variety out yielded the medium and long duration varieties. A medium duration variety (HD 229) had produced higher yield among the 1st December sown varieties. On the other hand, long duration variety (PBW 343) produced more yield among the varieties sown on 15th December (Fig.28).

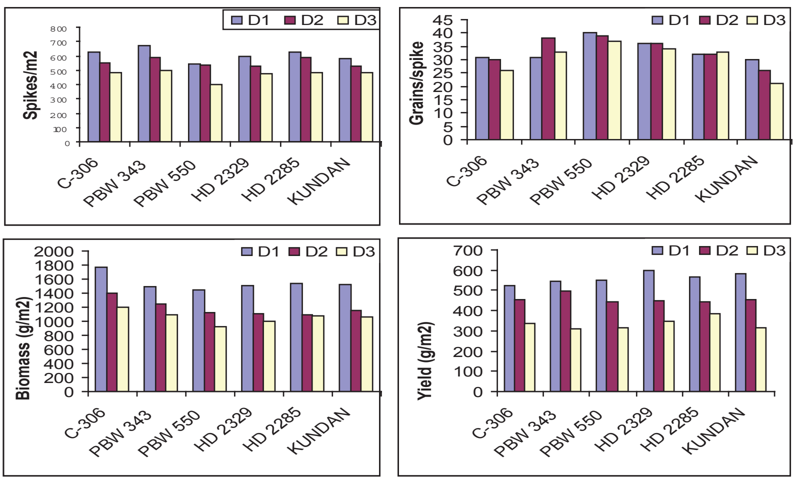


Fig.28. Performance of Wheat varieties of different maturity duration under varying dates of sowing

Objective: Assessing impact of climate change on pest dynamics and crop-pest interactions and linking pest population dynamics simulation models with InfoCrop model

a. Brown planthopper damage in rice

Impact of climate change on population dynamics of rice brown planthopper (BPH) and crop-pest interactions was analyzed through InfoCrop-rice coupled with pest population dynamics model. Hemimetabolous population dynamics model was adapted for BPH using species specific thresholds of development, thermal constants, and abiotic and biotic mortality factors. Values of threshold of development used were 10.4, 9.7, 9.7 and 8.9°C for egg, small nymphs, large nymphs and adults while corresponding thermal constant were 138, 114, 127 and 100 DD. Biotic mortality factors included egg infertility (26%), egg parasitism (30%), small nymph parasitism (30%) and large nymph predation (51%). Likewise, adverse effect of low and high temperature on development and survival of various pest stages was also taken in to account. Population dynamics model was calibrated and validated with field data on BPH population on rice in Delhi (Yadav *et al*., 2010) and Aduthurai. The model was initialized with the BPH population observed in the field experiments and run with experimental conditions such as weather, agronomic management etc. Observed and simulated BPH number were found to be quite close (R^2= 0.875; Fig. 29), indicating validation of the population dynamics model.

Further, coupled InfoCrop-rice was calibrated and validated for crop-pest interactions using BPH population and yield data in Delhi (Yadav *et al*., 2010) and Aduthurai. Observed and simulated yield under various BPH infestation levels were observed to be in good agreement (R^2= 0.874; Fig. 30) depicting appropriate simulation of population dynamics as well as yield loss by the coupled InfoCrop-rice.

Validated InfoCrop-rice model was used to simulate impact of climate change on the BPH population and crop-pest interactions using 2006 weather as a reference with 380 ppm CO_2. The model was then run with 0.5, 1.0 and 1.5°C rise in daily average temperature with 410 ppm CO_2, and with 2.0, 2.5 and 3.0°C rise in daily average temperature with 450 ppm CO_2.

Temperature increase of 0.5°C showed only a slight decrease in BPH population in different development stages. On the other hand, 1.0-3°C temperature rise over 2006 Delhi weather resulted in 14.25-61.06, 14.89-61.70 and 14.78-61.42% decline in egg, nymphal and adult population of BPH, respectively (Fig.31). The quantum of decrease increased with quantum of rise in temperature.

Yield of uninfested rice crop also declined with rise in daily average temperature by 0.5, 1.0 and 1.5°C (each under 410 ppm CO_2), and with 2.0, 2.5 and 3.0°C rise (under 450 ppm CO_2), indicating that climate might adversely affect rice yield under Delhi conditions. With 0.5-1.5°C temperature rise (under 410 ppm CO_2) yield ranged from 3308-3745 kg ha^{-1} compared to 3856 kg ha^{-1} with 2006 Delhi weather (380 ppm CO_2). More the temperature rise more was the yield decline. On the other hand, with 2.0-3.0°C temperature rise (450 ppm CO_2), crop yield ranged from 3012-3021 kg ha^{-1}. Temperature rise beyond 2.0°C (under 450 ppm) did not show any affect on crop yield. The crop duration also reduced with temperature rise.

In accordance with decline in BPH population, yield loss due to the pest showed a declining trend with intensity of climate change (Fig.32). The study thus showed that though climate change would adversely affect rice yield under Delhi conditions, relative yield loss due to BPH might decline.

b. Stem borer damage in rice

Holometabolous population dynamics model was adapted for pink borer using species specific thresholds of development, thermal constants, and abiotic and biotic mortality factors. Values of threshold of development used were 8.8, 7.2, 7.8 and 8.0^{o}C for egg, larval, pupal and adult stage while corresponding thermal constant were 124.8, 448.3, 142 and 80 DD. Coupled InfoCrop-rice was calibrated and validated for crop-pest interactions using field experiment data (Reji *et al*., 2008).

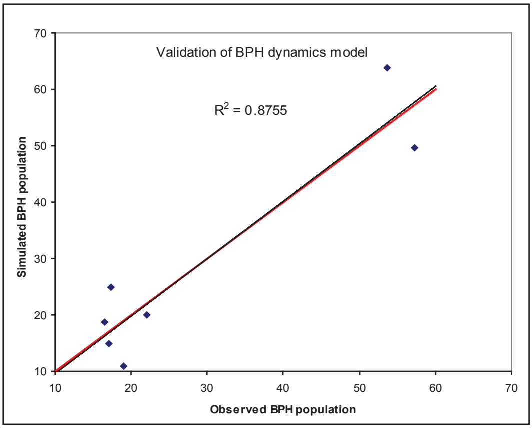
Validated InfoCrop-rice model was used to simulate impact of climate change on the pink borer population and crop-pest interactions, using 2007 weather as reference under 380 ppm CO_2. The model was then run with 0.5, 1.0 and 1.5^{o}C increase in daily average temperature under 410 ppm CO_2, and with 2.0, 2.5 and 3.0^{o}C rise in daily average temperature under 450 ppm CO_2.

Temperature increase of 0.5- 3^{o}C over 2006 Delhi weather depicted a decrease in the pink borer population in different development stages. The population decrease ranged from 6.8-52.7, 12.5-79.9 and 14.0-82.1% in egg, larval and pupal stage, respectively (Fig.33). The quantum of decrease increased with intensity of temperature rise.

Yield of uninfested rice crop also declined with rise in daily average temperature by 0.5, 1.0 and 1.5^{o}C (under 410 ppm CO_2), and with 2.0, 2.5 and 3.0^{o}C rise (under 450 ppm CO_2), indicating that climate might adversely affect rice yield under Delhi conditions. Like BPH, yield loss in rice due to stem borer also showed a declining trend with intensity of climate change (Fig.34).

c. Stem borer damage in wheat

Holometabolous population dynamics model adapted for pink borer using species specific thresholds of development, thermal constants, and abiotic and biotic mortality factors, was coupled to InfoCrop-wheat. The coupled model was then calibrated and validated for crop-pest interactions using field experiment data. Validated InfoCrop-wheat was used to simulate impact of climate change on the pink borer population and crop-pest interactions, using 2006-07 weather as reference with 380 ppm CO_2. Simulations were then done with 0.5, 1.0 and 1.5^{o}C increase in daily average temperature under 410 ppm CO_2, and with 2.0, 2.5 and 3.0^{o}C rise in daily average temperature under 450 ppm CO_2. Temperature increase of 0.5- 3^{o}C over 2006-07 Delhi weather depicted an increase in larval population of the pink borer (Fig.35). The quantum of population rise increased with intensity of temperature rise. Wheat yield was found to be higher with 0.5, 1.0 and 1.5^{o}C (410 ppm CO_2), and 2.0^{o}C rise (450 ppm CO_2) compared to that during 2006-07 indicating that climate change might increase wheat yield initially. However, yield with 2.5 and 3.0^{o}C (450 ppm) was lower that that during 2006-07. Unlike BPH and stem borer in rice, yield loss in wheat due to pink borer might increase (Fig.36).



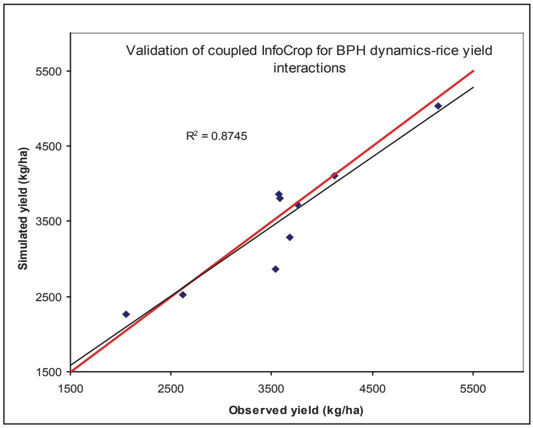


Fig.29. Validation of brown planthopper population dynamics model

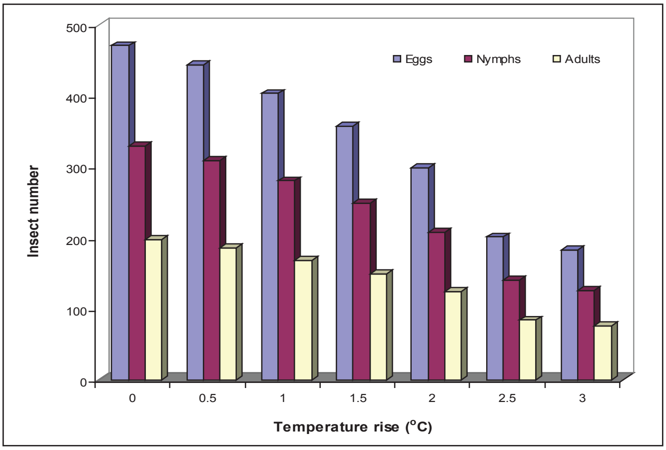


Fig.30. Validation of coupled InfoCrop-rice for BPH population-rice

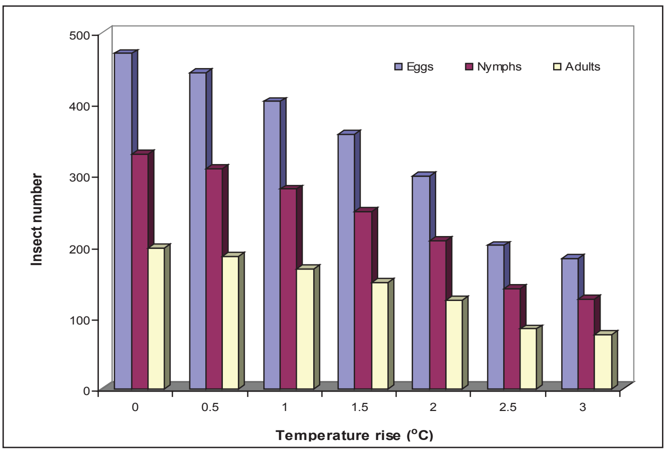


Fig.31. Effect of global warming on BPH population (progeny of 10 adults) as simulated with population dynamics model with reference to 2006 Delhi weather

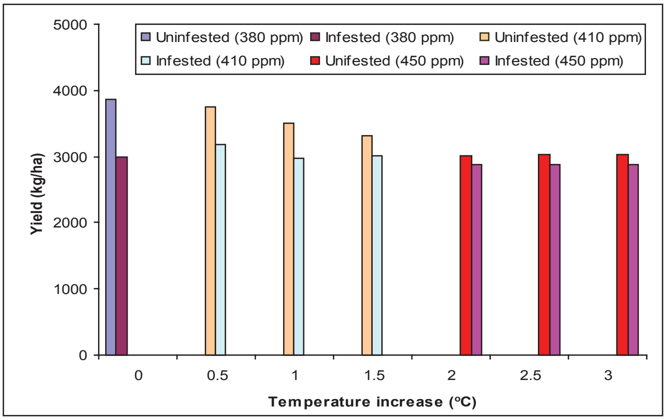


Fig.32. Effect of climate change on rice yield under brown planthopper stress as simulated with coupled InfoCrop-rice model with reference to 2006 Delhi weather

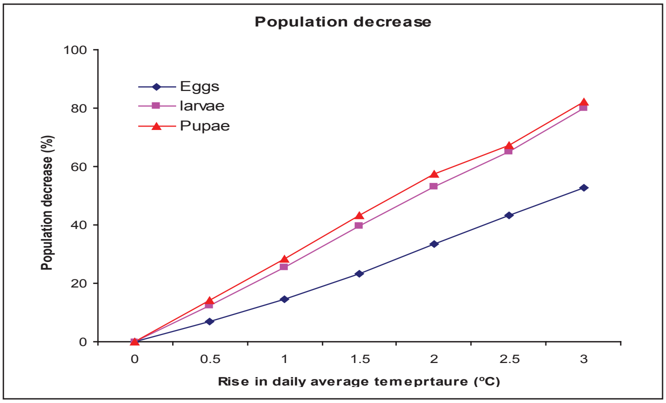


Fig.33. Effect of global warming on pink stem borer population on rice as simulated with population dynamics model with reference to 2007 Delhi weather

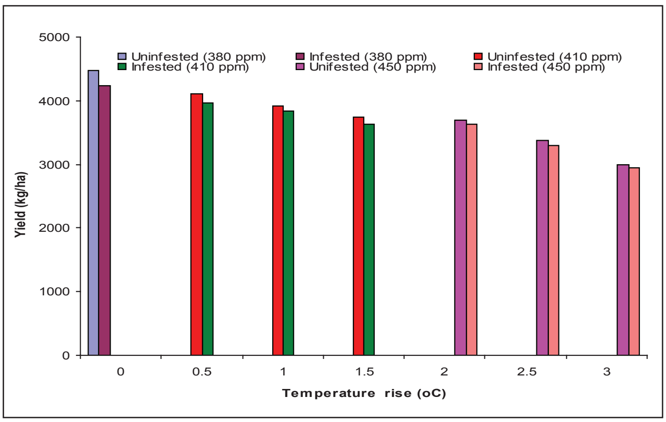


Fig.34. Effect of climate change on rice yield as simulated with coupled InfoCrop-rice under stem borer stress with reference to 2007 Delhi weather

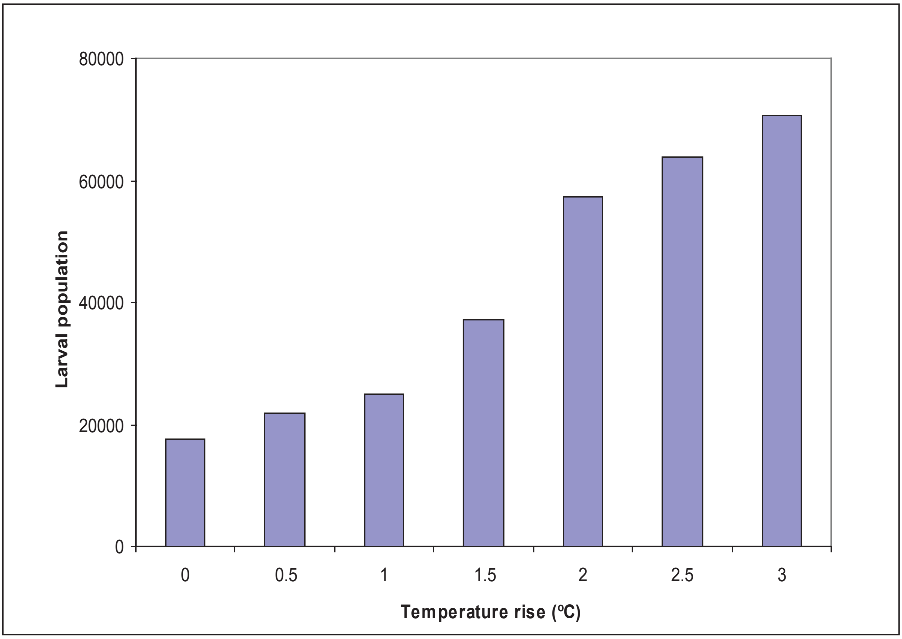


Fig.35. Effect of global warming on pink borer population in wheat as simulated through population dynamics model with reference to 2006 Delhi weather

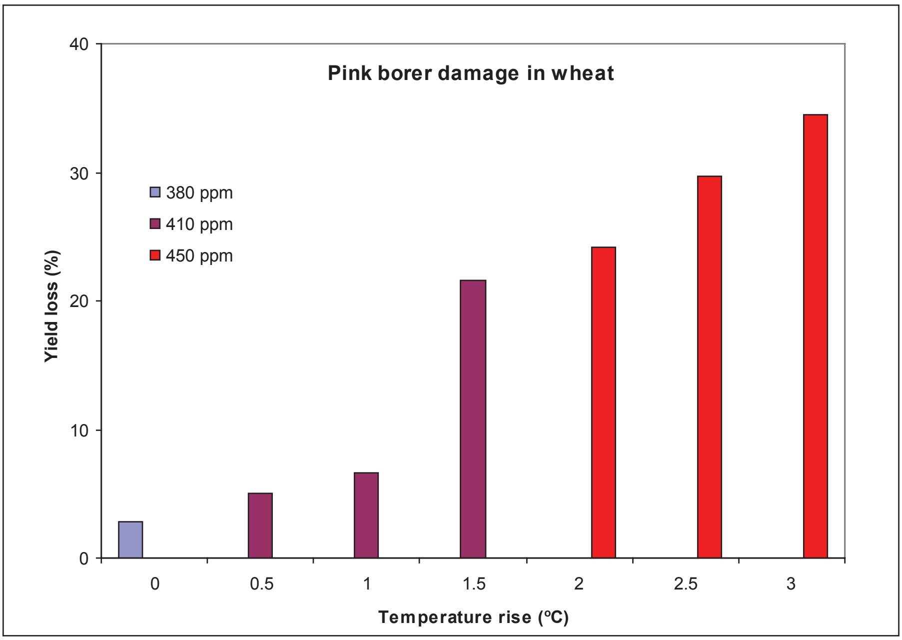


Fig.36. Effect of climate change on yield loss in wheat due to pink borer as simulated with coupled InfoCrop-wheat with reference to 2006-07 Delhi weather

Objective: **To assess the impact of elevated temperature and carbon dioxide on emissions of GHGs and preparation of inventory of CO_2 emission from crop residue burning and their mitigation from soils**

Impact of elevated CO_2 on green house gas (GHG) emission

Field measurement of methane (CH_4) and nitrous oxide (N_2O)emissions was carried out during the *kharif* season in rice while measurement of nitrous oxide and carbon dioxide (CO_2) was carried out during *rabi* season in chickpea and wheat crops grown in free air carbon dioxide enrichment (FACE, 500ppm CO_2) rings. The cumulative flux of methane in rice grown under 550 ppm CO_2 in FACE increased from 22 to 59 kg ha^{-1} (Table.8). The cumulative nitrous oxide flux was lower under elevated carbon dioxide conditions. Reduced nitrate concentration was observed in rice soil under elevated carbon dioxide concentration in FACE which resulted in a significant decline in nitrous oxide emission as compared to ambient carbon dioxide levels. There was no significant change in soil organic carbon in rice under elevated carbon dioxide.

Table 8. Impact of elevated carbon dioxide (FACE) on methane & nitrous oxide emission (kg ha^{-1}) from rice soil

	CH_4 (kg ha^{-1})	N_2O-N (g ha^{-1})
Ambient	21.8 ± 2.22	604 ± 44
FACE	59.3 ± 21.8	324 ± 54

The nitrous oxide flux increased in FACE soil as compared to ambient soil in chickpea whereas the reverse was observed in case of wheat. Lower nitrate levels were observed during the crop growth period in wheat under FACE soil as compared to ambient soil whereas as no significant change in nitrate was observed in chickpea crop. The cumulative flux of nitrous oxide emission in wheat and chickpea is shown in Table.9.

Table 9. Impact of elevated carbon dioxide (FACE) on nitrous oxide emission (g ha^{-1}) from chickpea and wheat soil

	N_2O-N (g ha^{-1})	
	Chickpea	Wheat
Ambient	591 ± 15	926 ± 44
FACE	642 ± 22	632 ± 20

The cumulative carbon dioxide emission in chickpea was approximately 10% higher under elevated carbon dioxide (FACE) in chickpea at 690 kg CO_2-C ha^{-1} as compared to 610 kg CO_2-C ha^{-1} under ambient CO_2 conditions. The temporal change in the CO_2 emission in chickpea is shown in Fig.37. There was no significant change in soil organic carbon under elevated carbon dioxide conditions in FACE in both wheat and chickpea.

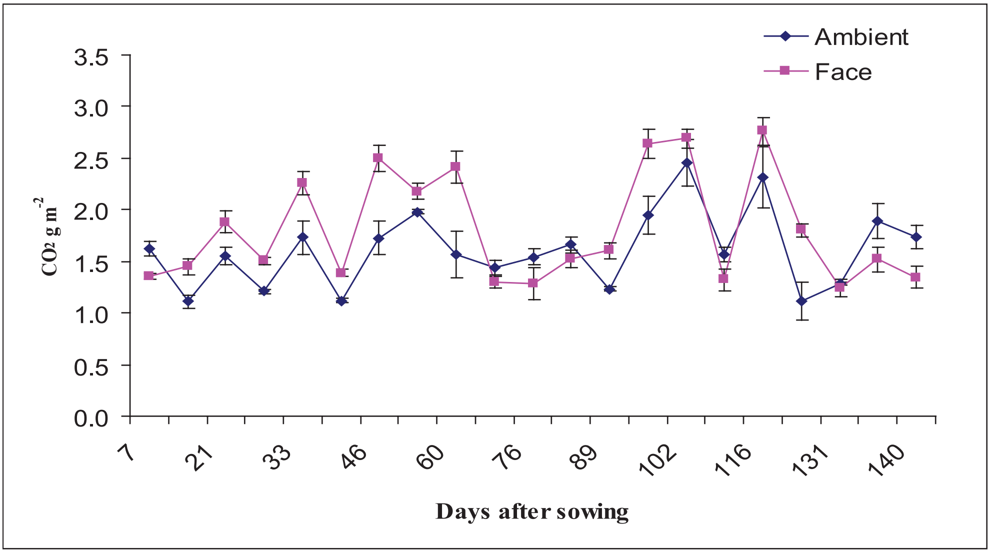


Fig.37. Impact of elevated carbon dioxide (FACE) on temporal emissions of carbon dioxide (g m^{-2}) from soil in chickpea

Greenhouse gas emission due to burning of crop residues

Biomass burning is an important source of trace gases and aerosols to the atmosphere. Crop residue is burned in the fields in many Indian states particularly in Punjab, Haryana and western Uttar Pradesh producing CO, CH_4, N_2O, NOx, NMHCs, SO_2 and many other gases. Non-CO_2 emissions from crop residue burning were calculated using the following equation.

$$FBCR = \Sigma crops\ (A \times B \times C \times D \times E \times F)$$

Where, FBCR= Emissions from residue burning, A = Crop production, B = Residue to crop ratio, C = Dry matter fraction, D = Fraction burnt, E = Fraction actually oxidized and F = Emission factor

Generally, residues from nine crops (rice, wheat, cotton, maize, millet, sugarcane, jute, rapeseed-mustard and groundnut) are burned in field. The emission of various nitrogenous species quantified by estimating the amount of biomass burnt in the field using the IPCC inventory preparation guidelines (IPCC, 1996, 2006). State-wise crop production data were obtained from MoA (2008). Total residue generated by nine major crops was estimated to be 506.03 million tons (Table.10) and 79.55 million tons is subjected to burning in the field. Rice straw, sugarcane leaves and wheat straw are the main source of burning of agricultural wastes and contribute 33%, 28% and 24% respectively of the total crop residue that is subjected to burning (Fig.38). Using ratio of residue to economic yield, fractions of residues burned in field, fraction of residues oxidized and the emission factors for methane and nitrous oxide, emission estimates of these gases from residue burning were calculated. Burning of crop residue in field in India emitted 214.8 Gg of CH_4 and 5.6 Gg of N_2O in 2007.

Table.10. Emission of methane and nitrous oxide from burning of crops residues in field

Crop	Production (Mt)	Residue generated (Mt)	Residue burned in the field	Methane (Gg)	Nitrous oxide (Gg)	CO_2 Equivalent (Gg)
Rice	93.4	120.4	26.61	71.9	1.9	2350.78
Wheat	75.8	114.6	19.10	51.6	1.3	1688.32
Maize	15.1	19.9	1.79	4.8	0.1	159.74
Jute	18.6	31.9	2.56	6.9	0.2	226.14
Cotton	38.5	54.3	4.35	11.7	0.3	382.65
Groundnut	4.9	7.8	0.62	1.7	0.0	54.17
Sugarcane	355.5	125.9	22.03	59.5	1.5	1946.17
Rapeseed & Mustard	3.3	8.0	0.64	1.7	0.1	58.15
Millets	17.5	23.1	1.85	5.0	0.1	163.49
Total	622.53	506.03	79.55	214.8	5.6	7029.61

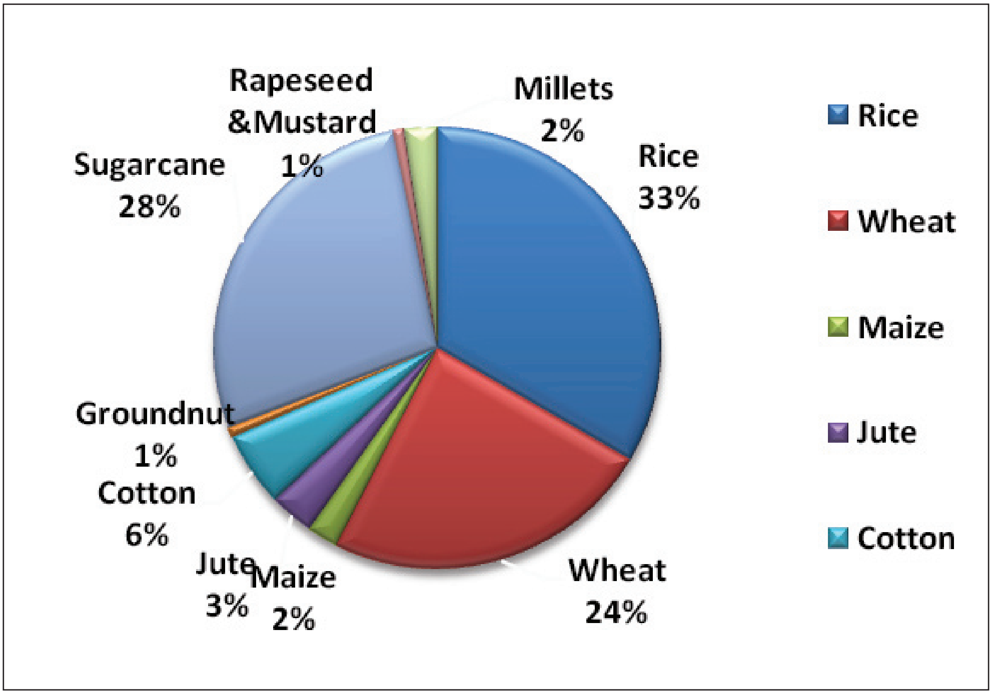


Fig.38. Cropwise residue burned in the field

Greenhouse gas emission mitigation potential of system of rice intensification

A field experiment was conducted to assess the impact of system of rice intensification on methane and nitrous oxide emission as compared to conventional practice of growing rice in the farms of Indian Agricultural Research Institute (IARI), New Delhi in *kharif* 2009. The experiment was carried out by growing rice (var. Pusa 44) under System of rice intensification (SRI) and conventional practice. In SRI 12 day's old seedlings were transplanted with plant to plant spacing of 20 x 20 cm. Emission of methane ranged from 3.4-488 g /ha /d in different treatments. During initial stages, SRI technique recorded higher methane emission than conventional transplanting. The increased methane emission in SRI establishment technique at initial stages can be attributed to planting of young seedlings at wider spacing (20 cm x 20 cm) under puddled condition, which lead to large root volume, more tillers resulting in more biomass and more methane. The seasonal integrated flux of methane was 21.4 and 8.1 kg/ha/season from conventional transplanting and SRI respectively (Table.11). Methane emission was reduced by 62% in SRI. Emission of nitrous oxide ranged from 1.2 to 29.95 g /ha /d in different treatments. The seasonal integrated flux of nitrous oxide was 1.058 and 1.399 kg/ha/season from conventional transplanting and SRI respectively. The emission of nitrous oxide was found to increase by 32% in case SRI as compared to conventional treatment. This increase in nitrous oxide can be attributed to continuous aerobic and anaerobic conditions prevailing in SRI leading to emission by both nitrification and denitrification process. In terms of global warming potential (GWP), a reduction of 27.24% was observed in system of rice intensification despite the increase in nitrous oxide.

Table 11. Emission of nitrous oxide and methane their total global warming potential in SRI and conventional system

Treatment	Emissions from rice (kg/ha)		GWP	% Reduction in GWP	Cost of GWP reduction Rs/ha		
	N_2O	CH_4	Kg CO_2/ha		@$10/t CO_2	@$20/t CO_2	@$30/t CO_2
SRI	1.059	21.41	850.71		291	582	873
Conventional transplanting	1.399	8.08	618.96	27.24	400	800	1200

System of rice intensification reduced the water requirement for rice cultivation by 44%. The total cost of cultivation for both conventional as well as SRI was also calculated. A benefit of Rs. 6336 - 6554 /ha can be achieved in system of rice cultivation depending on the cost of per carbon dioxide trading (Table12). At present the transaction cost is not included while calculating the cost benefit of the two practices.

Table 12. Water saving and Cost benefit of SRI and conventional system

Treatment	Water requirement cubic meter	Cost of cultivation Rs/ha		Benefit Rs/ha	Benefit compared to conventional Rs/ha
		Input cost	Output cost		
SRI	9800	29783	59014	29231	6227
Conventional transplanting	17500	38889	61893	23003	

Objective: Assessing the impact of high temperature on evolution / adaptation of microbial population

Impact of high temperature on microbial population

Temperature is considered as a key environmental variable, as it exerts a controlling influence on nearly all physiological rate processes of an organisms and thereby affects the growth and reproduction. Microbes are increasingly being used as a model system to test various hypothesis of evolutionary and adaptation mechanisms. Four different strains of *Pseudomonas fluorescens* (tentatively identified) namely Strain 1, 1.1, 1.2 and 2 were isolated from the chickpea rhizosphere on the King's base medium. Continuing with the previous studies, we would like to test the hypothesis that whether the population of *Pseudomonas* strain 1.2, when encountered the novel environment of 35°C or 40°C has adapted to these new circumstances. Adaptation here means an improvement in fitness of the population relative to its original (=ancestral) condition when it first entered the new environment. We measured the absolute fitness of each ancestral and derived genotype at the 28°C, 30°C, 35°C and 40°C.

The ancestral genotype persisted at 28 and 30°C, but it failed to persist further, thereby limiting the upper thermal limit to 30°C. Thus the ancestral thermal limit is from 20 to 30°C. By contrast, the line evolved at 35°C persisted till 40°C, whereas one of 40°C line persisted to 45°C. The high temperature for the ancestral range inhibited the growth; whereas evolved lines could tolerate the higher temperatures (Fig.39).

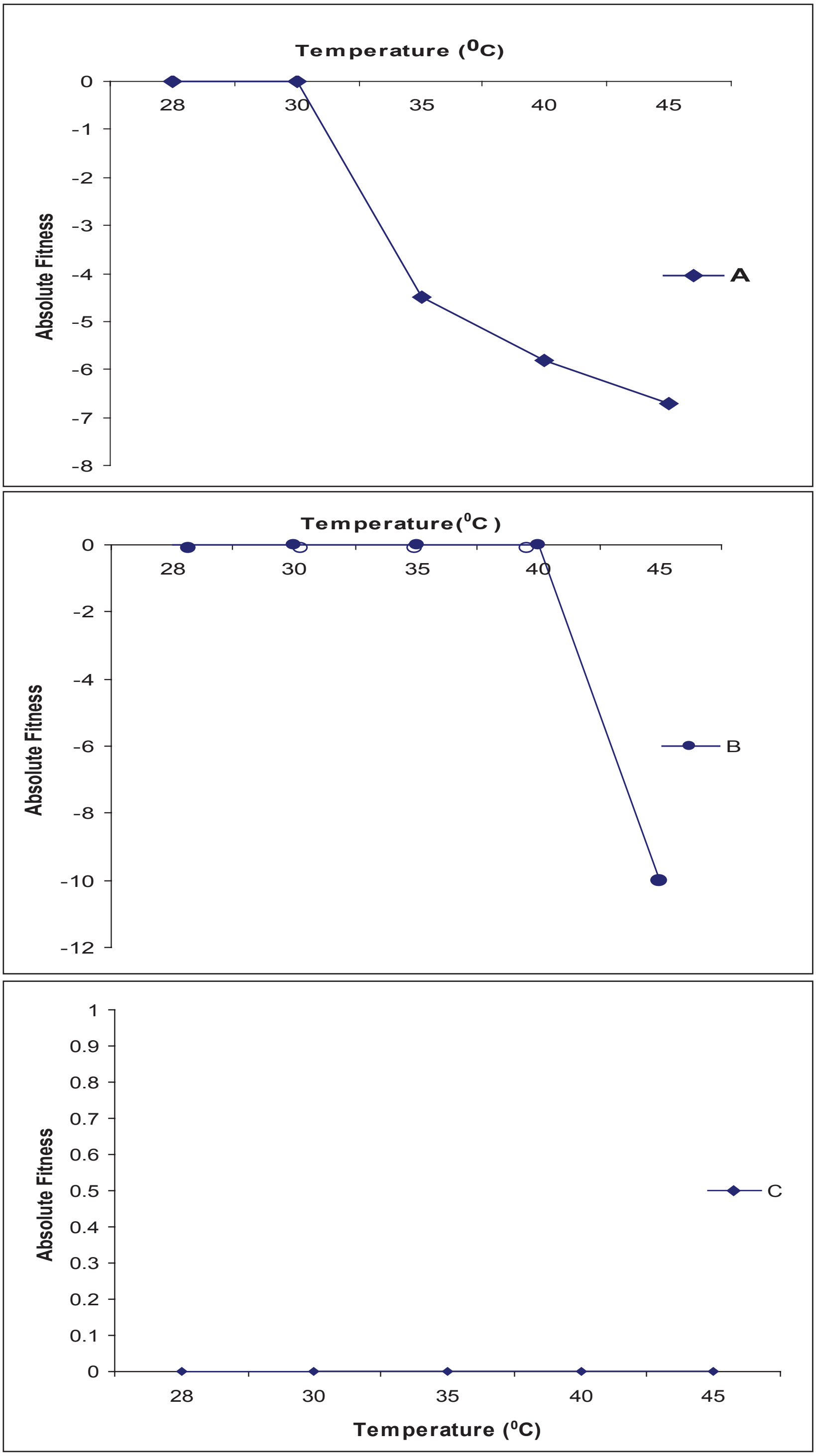


Fig.39. Absolute fitnesses of three genotypes between 28°C and 45°C. (A) Common ancestor (B) one of six lines evolved at 35°C (C) one of six lines evolved at 40°C

CENTRAL RESEARCH INSTITUTE FOR DRYLAND AGRICULTURE

HYDERABAD

Objective: To assess the impact of climate change on major food crops viz., maize and rice in Andhra Pradesh

Impact of climate change on maize crop and adaptation strategies

It is important to analyze the consequences of climate change on maize productivity in major growing producing regions of Andhra Pradesh state and elucidate potential adaptative strategy to minimize adverse effects. Maize model of INFOCROP group which is calibrated and validated was used for simulating and analyzing the impacts of increase in temperature and carbon dioxide (CO_2) and change in rainfall from the HadCM3 A2 a scenario for 2020, 2050, 2080. In order to assess the climate change impact in the major maize growing areas, five representative stations from three different agroclimatic zones of Andhra Pradesh were selected. Low or no additional cost adaptation strategies to reduce the effect of climate change have been used *viz.,* change in date of sowing, suitable crop variety (by adjusting the duration of the crop in the model).

Impacts of climate change on maize yield

The impact analysis was done with coupled HadCM3 A2 a scenario for 2020, 2050, 2080 to baseline values. Analysis reveals that in Ranga Reddy area, the monsoon season maize yield is projected to reduce by 5%, 18% and 13% from the present yields due to projected climate scenarios during the period 2020, 2050 and 2080, respectively (Fig.40). In Medak area, maize yield is projected to lose by 4% from current yield due to climate change by 2020, 22% by 2050 and 9% by 2080 (Fig.41). In Karimnagar area, maize yield was projected to reduce by 3%, 11% and 18% from current yield due to climate change by 2020, 2050 and 2080, respectively (Fig.42). In Warangal area, maize crop is to lose grain yield by 10% from current yield due to climate change by 2020, 17% by 2050 and 28 % by 2080 (Fig.43).

Analysis of adaptation strategies of climate change on maize yield

The adaptation strategies which were simulated in the model helped the maize crop to recover from the yield loss due to projected climate change. The crop is positively responded and the yields were increased in the tune of 6%, 1%, 2% and 5% in Ranga reddy, Medak, Jagitial and Warangal, respectively in 2020. The yield loss was reduced by 5%, 15%, 6% and 3% in Ranga reddy, Medak, Jagitial and Warangal, respectively during 2050 impact. Further, during, the adaptation strategies improved the grain yield by 10%, 12%, 9% and 8% in Rangareddy, Medak, Jagitial and Warangal, respectively during 2080 projected impacts (Fig. 40 – 43).

Vulnerability of maize crop for projected climate change scenarios

After analyzing the impact and adaptation strategies for maize crop still there is loss of grain yield observed at many places. The net vulnerability on maize even after adaptation in respective scenario was obtained as net vulnerability (yield loss%, even after adaptation, from baseline) = yield gain after adaptation (%) + Impact (yield loss due to climate change (%)). It was observed from the above analysis, at Warangal there is still 5% yield loss was observed in 2020 where as the remaining stations were out of the vulnerable zone. The vulnerability of the crop is still existed by -13%, -7%,-5% and -14% in the Rangareddy, Medak, Jagitial and Warangal areas respectively during 2050. The crop vulnerability further observed during 2080 at a tune of -3%, -9%, and -20% in Ranga reddy, Jagitial and Warangal, respectively (Fig. 40 – 43). These vulnerabilities will be managed by the good management practices like application of extra amount of fertilizers and timely inter cultural operations, applying mulches and timely irrigation (if available).

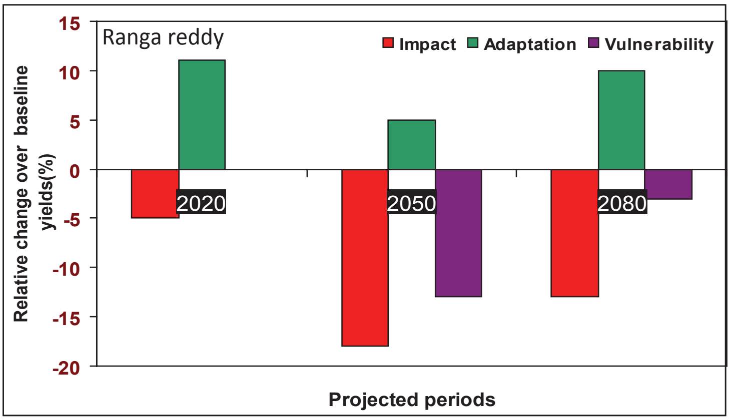


Fig.40. Impact, adaptation and net vulnerability of maize yield to 2020, 2050 and 2080 HadCM3 scenarios in Rangareddy

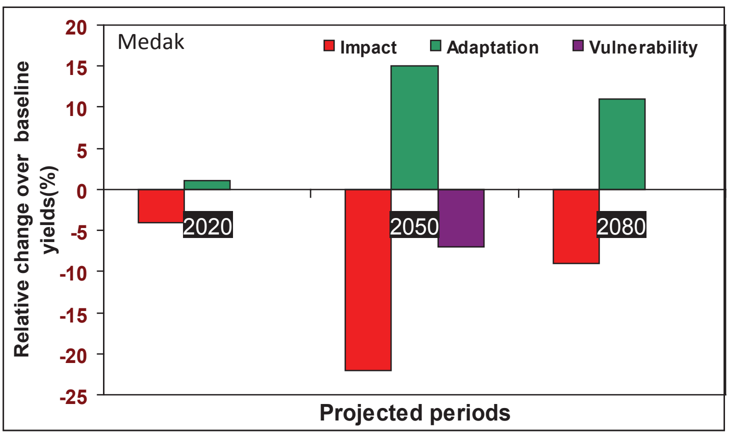


Fig.41. Impact, adaptation and net vulnerability of maize yield to 2020, 2050 and 2080 HadCM3 scenarios in Medak

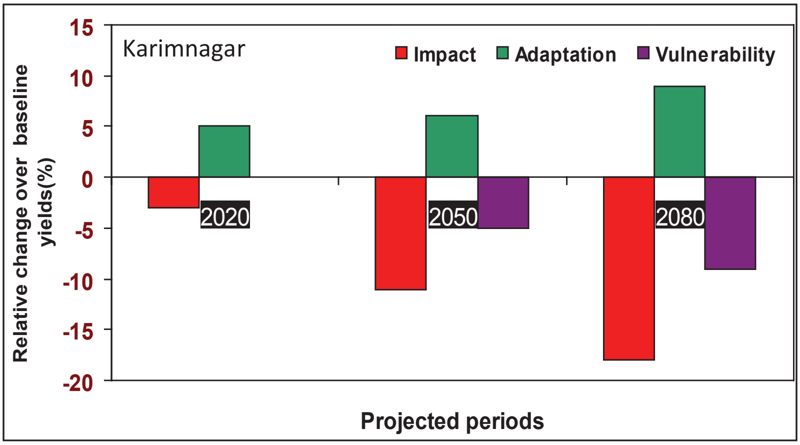


Fig.42. Impact, adaptation and net vulnerability of maize yield to 2020, 2050 and 2080 HadCM3 scenarios in Karimnagar

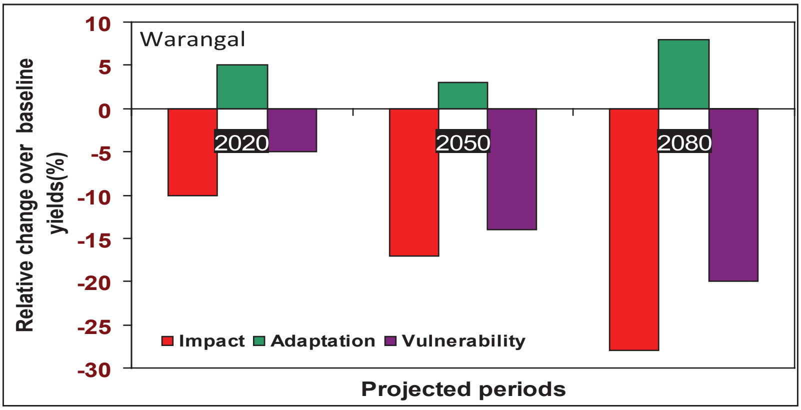


Fig.43. Impact, adaptation and net vulnerability of maize yield to 2020, 2050 and 2080 HadCM3 scenarios in Warangal

Impact, adaptation and vulnerability of rice crop to projected climate change

Impact of climate change on rice crop and adaptation strategies

It is important to analyze the consequences of climate change on rice productivity in major growing producing regions of Andhra Pradesh state. Rice model of INFOCROP group which is calibrated and validated was used for simulating and analyzing the impacts of increase in temperature and carbon dioxide (CO_2) and change in rainfall from the HadCM3 A2a scenario for 2020, 2050, 2080. In order to assess the climate change impact in the major rice growing areas, representative stations from different agroclimatic zones of Andhra Pradesh were selected. Low or no additional cost adaptation strategies to reduce the effect of climate change have been used *viz.,* change in date of sowing.

Impacts of climate change on rice yield

The impact analysis was done with coupled HadCM3 A2a scenario for 2020, 2050 and 2080 to baseline values. Analysis reveals that in Rangareddy area, the monsoon season rice yield is projected to reduce by 3.4%, 6.8% and 11.6% from the present yields due to projected climate scenarios during the period 2020, 2050 and 2080, respectively (Fig.44). In East Godavari area, yield of rice crop is reduced by 1.9% from current yield due to climate change by 2020, 9.5% by 2050 and 13.5% by 2080 (Fig.45). In Krishna area, rice yield reduce by 6.1% and 8.6% from current yield due to climate change by 2050 and 2080, respectively (Fig.46). In Guntur area, grain yield of rice crop reduced by 0.3% from current yield by 2020, 3.9% by 2050 and 6.8% by 2080 (Fig.47).

Analysis of adaptation strategies of climate change on rice yield

The adaptation strategies which were simulated in the model helped the rice crop to recover from the yield loss due to projected climate change. The crop is positively responded and the grain yields were increased at a tune of 1.15%, 1.5%, 0.4% and 2.2% in Ranga reddy, East Godavari, Krishna and Guntur, respectively in 2020. The yield is increased by 2.7%, 3.5%, 2.6% and 1% in Rangareddy, East Godavari, Krishna and Guntur, respectively during 2050. Further the adaptation strategies improved the grain yield by 1.6%, 1.4%, 0.7% and 1.1% in Rangareddy, East Godavari, Krishna and Guntur, respectively during 2080 (Fig.44 - 47).

Vulnerability of rice crop for projected climate change scenarios

The vulnerability analysis suggests that, at Ranga reddy there - 2% yield loss was observed in 2020 where as the remaining stations were out of the vulnerable zone. In 2050, vulnerability of the crop is -4%, -6%,-3.6% and -3% in the Rangareddy, East Godavari, Krishna and Guntur areas, respectively. The crop vulnerability further observed during 2080 at a tune of -10%, -12%, -7.9% and -6% in Rangareddy, East Godavari, Krishna and Guntur, respectively (Fig.44 - 47).

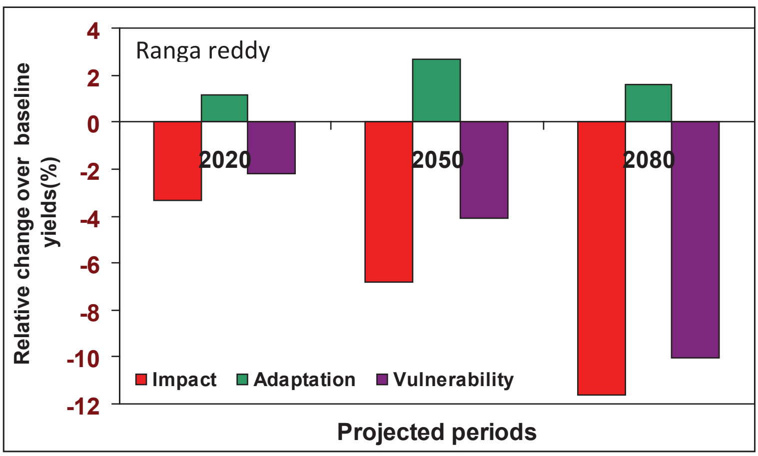


Fig.44. Impact, adaptation and net vulnerability of rice yield to 2020, 2050 and 2080 HadCM3 scenarios in Ranga reddy

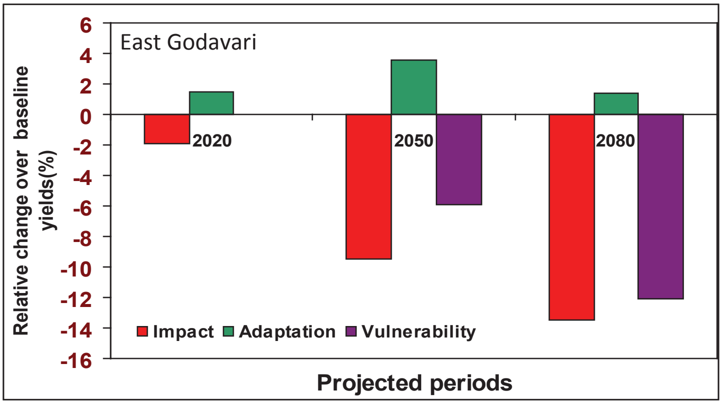


Fig.45. Impact, adaptation and net vulnerability of rice yield to 2020, 2050 and 2080 HadCM3 scenarios in East Godavari

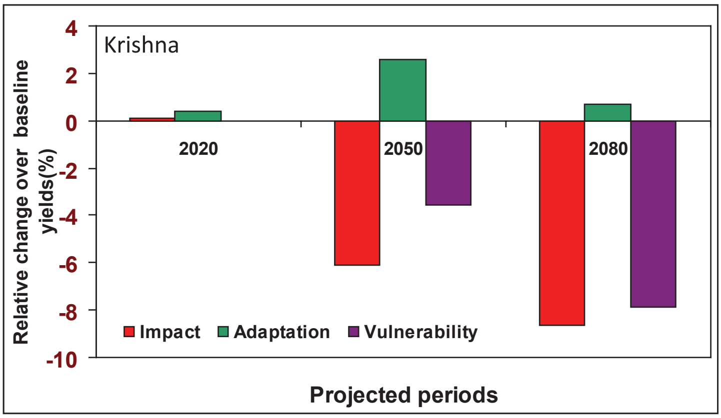


Fig.46. Impact, adaptation and net vulnerability of rice yield to 2020, 2050 and 2080 HadCM3 scenarios in Krishna

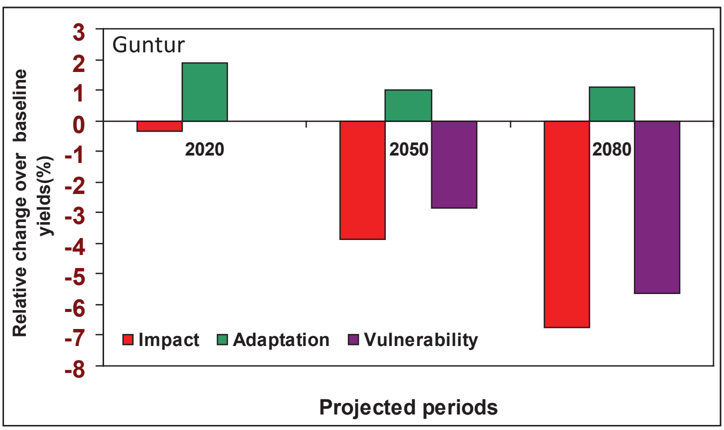


Fig.47. Impact, adaptation and net vulnerability of rice yield to 2020, 2050 and 2080 HadCM3 scenarios in Guntur

Objective: Extreme event analysis for rainfall and temperature for Andhra Pradesh

a. Heavy rainfall analysis

Trends in heavy rainfall events using IMD (1°X1°) girdded daily rainfall data of Andhra Pradesh State for three categories *viz.,* 50-75 mm/day, 75-100 mm/day and more than 100 mm/day were worked out on annual basis. The results revealed that increasing trend is observed in Kadapa and Nellore in Southern zone, border of Krishna and Guntur district in Krishna zone, East Godavari in Goadavari zone, Khammam and border of Warangal and Nalgonda district under 50-75 mm category. Under 75-100 mm category increasing tendency is noticed in Guntur and Visakhapatnam district. Increasing trend is seen in Khammam district under more than 100 mm category (Fig.48).

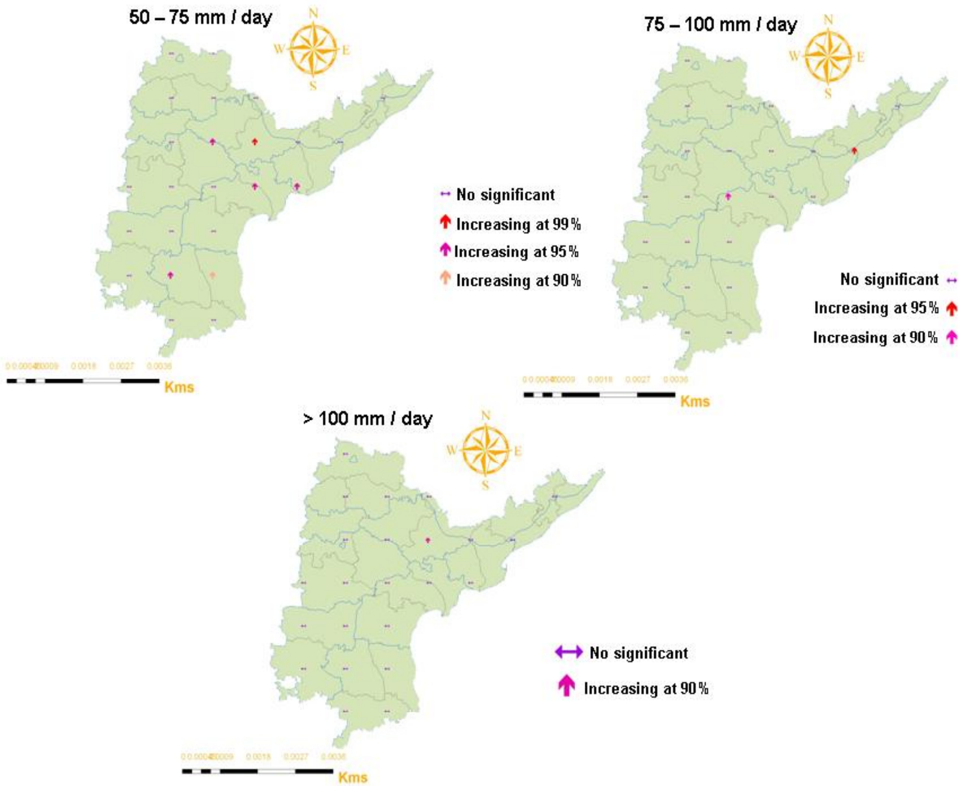


Fig.48. Trend in heavy rainfall events of Andhra Pradesh State

b. Trend in high maximum temperature (>40°C) and low minimum temperature (<10°C) temperature over Andhra Pradesh

Trend analysis has been done to know whether days with maximum temperature of above 40°C during March – June months is increasing or decreasing. The study indicated that during the months of April and June, significant trend is not noticed. However, in the month of March, days with above 40°C is increasing in Kurnool and Mahabubnagar district and declining trend in Adilabad district. In the month of May, increasing tendency was observed in Kadapa and Anantapur district (Fig.49).

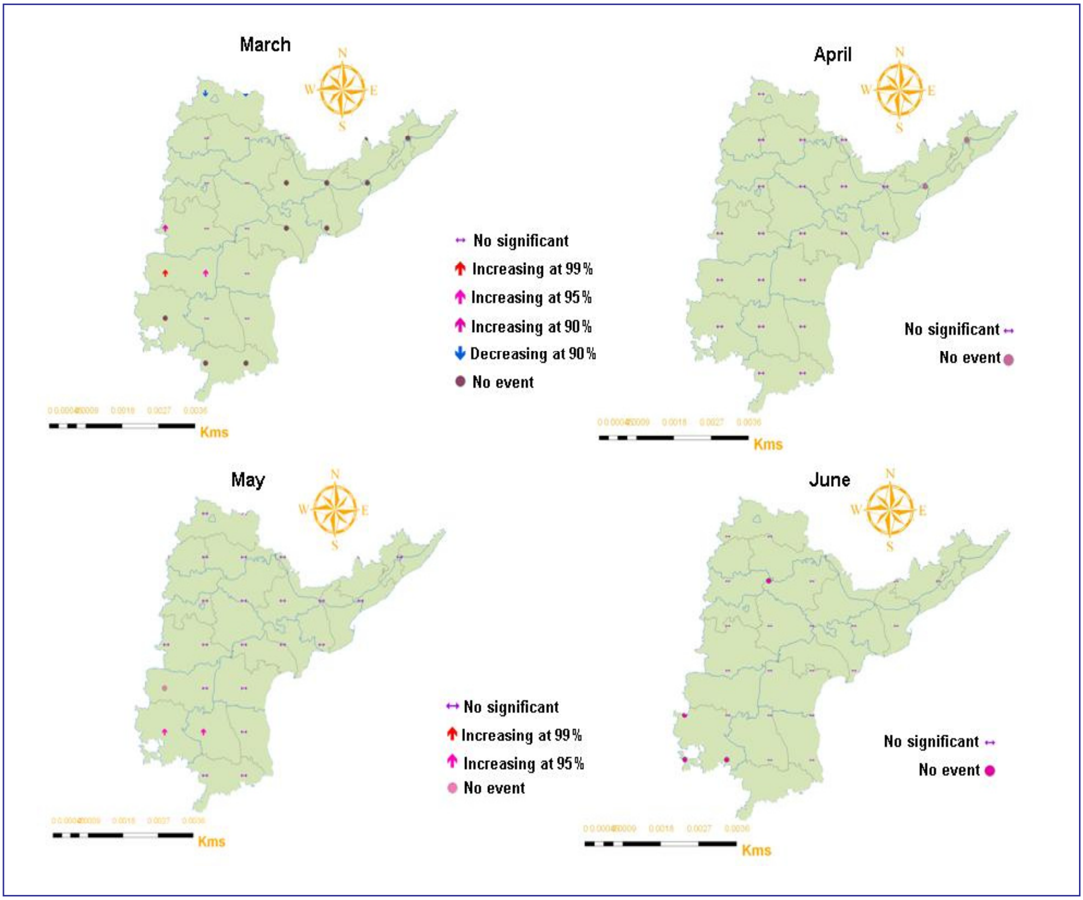


Fig.49. Trend in frequency of occurrence of above 40°C in Andhra Pradesh

c. Annual rainfall trend in India (1957 – 2007)

Significant rainfall increasing trend is noticed in entire West Bengal, central coastal and south western of Andhra Pradesh and central Tamil Nadu. Significant decreasing trend is observed in central part of Jammu & Kashmir, northern most of Madhya Pradesh, Central & western part of UP and northern & central part of Chhattisgarh (Fig.50).

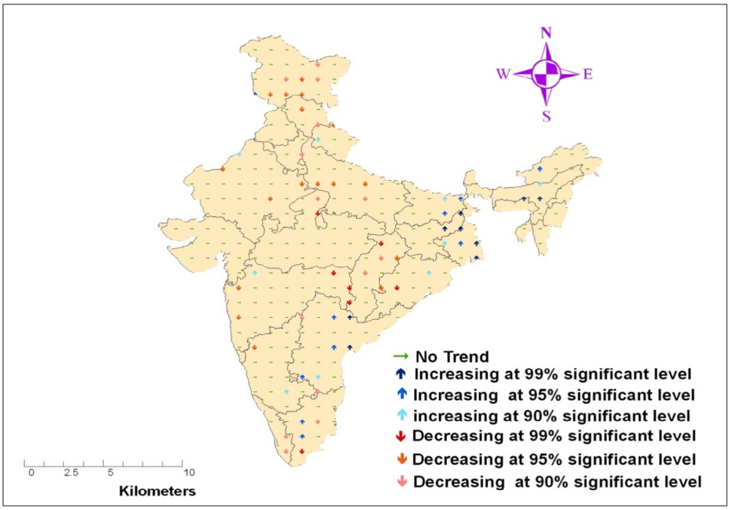


Fig.50. Annual rainfall trends over India (1957 – 2007)

d. Rainy days trend in India (1957 – 2007)

Rainy days declining trend is observed mainly in central India covering Chhattisgarh, Maharashtra and Madhya Pradesh, Jammu & Kashmir state in north and Kerala in south India. Increasing trend is noticed in south Andhra Pradesh, West Bengal and east and north east of Jammu & Kashmir state (Fig.51).

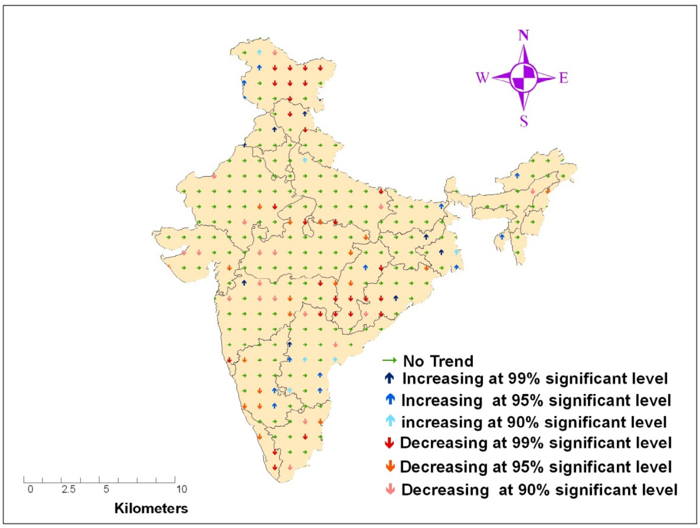


Fig.51. Annual rainy days trends over India (1957 – 2007)

Decadal changes in rainfall and rainy days over Andhra Pradesh

Study on decadal changes in annual rainfall revealed that slight variability of rainfall was observed in the last decade over Andhra Pradesh (Fig.52). However, the decade 1981-1990 was good, as most of area received above normal rainfall except some parts in southern Telangana and Rayalaseema region. Rainfall situation during 1991-2000 was consistent and followed normal pattern where as the current decade 2000-2009 witnessed worst drought years during 2002, 2009 and 2004. In the case of decadal variation in rainy days, it has followed the decadal rainfall changes pattern (Fig.53).

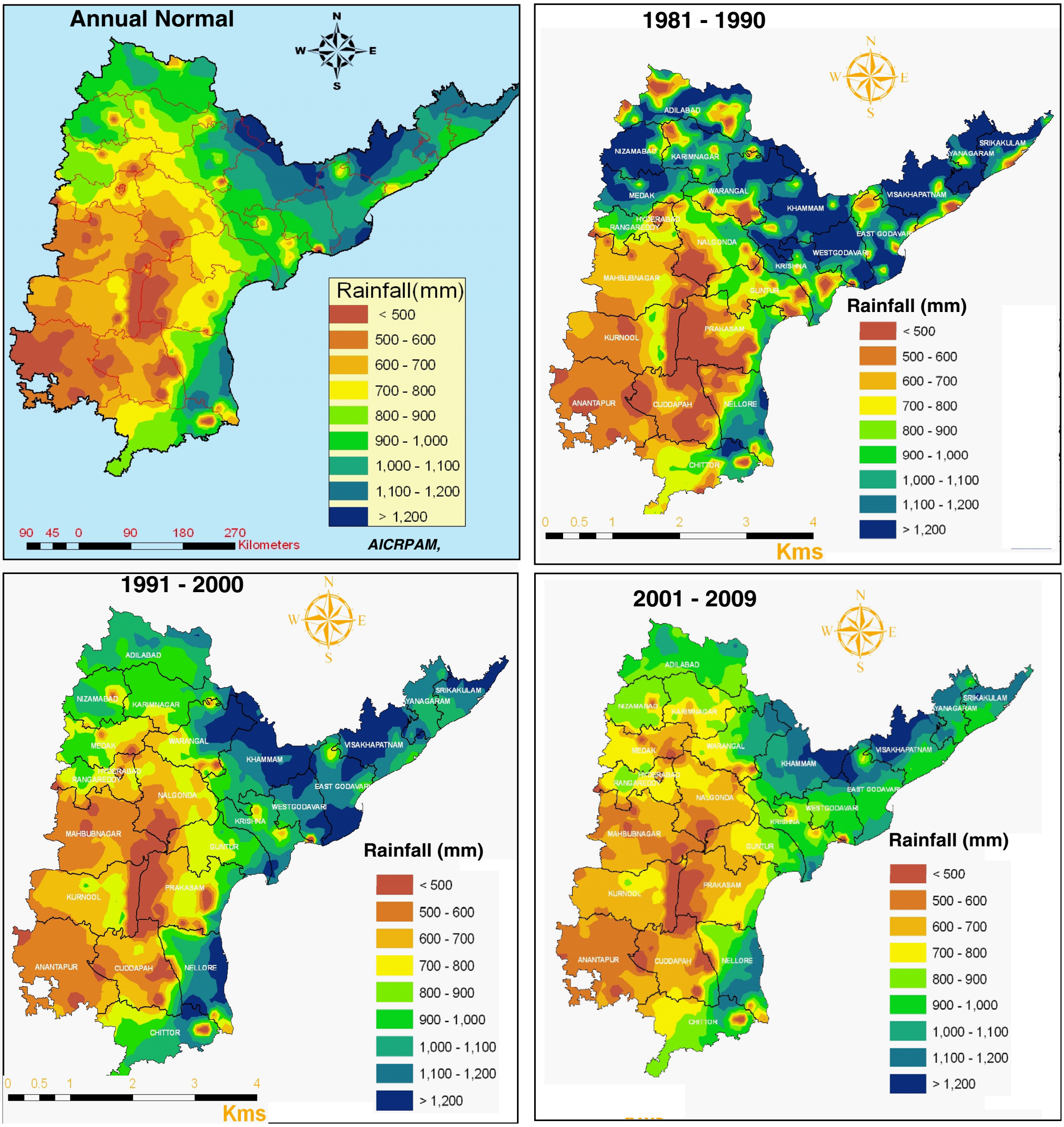


Fig.52. Decadal changes in annual rainfall over Andhra Pradesh

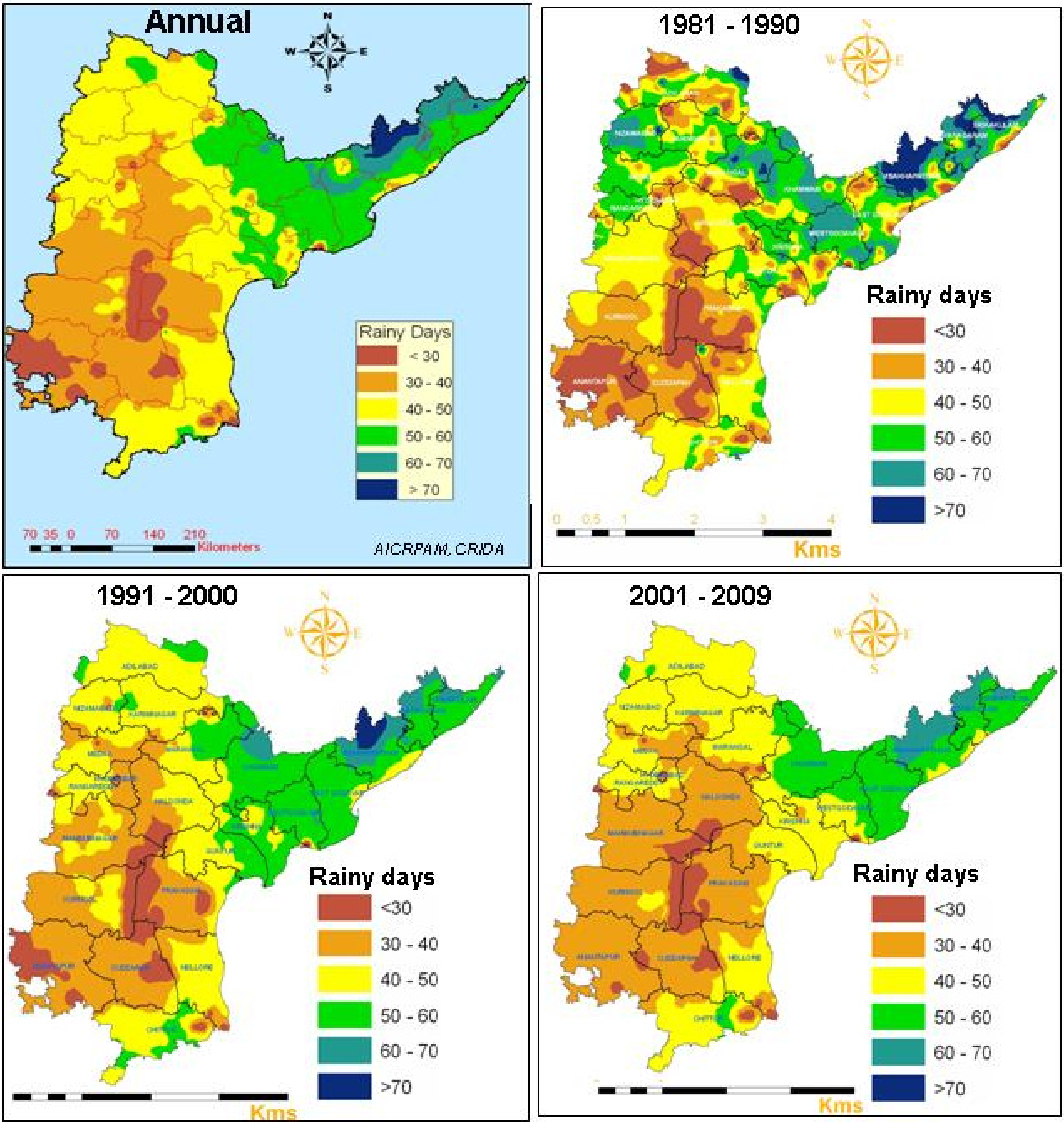


Fig.53. Decadal changes in annual rainy days over Andhra Pradesh

Farmers' awareness programme

To create awareness on climate change among farmers, an awareness program was conducted at Agricultural Research Station, Anantapur on 23-03-2010. About 100 farmers from Kalyandurg, Dharmavaram and Tadipatri mandals have attended the programme. They were exposed to Agromet instruments and explained their use in collection of data, relationship with agriculture and also appraised about the climate change and their possible impact on agriculture, horticulture, forestry, livestock, poultry and fishery production. Farmers were given with questionnaire prepared by NPCC & AICRPAM, CRIDA to fill up the same Feedback was collected and their queries were answered. Three best farmers were identified and given prizes as an encouragement.

- In the center majority of the farmers (58%) identified rainfall is the most important parameter influencing the Agricultural production in Anantapur region.
- Next to rainfall, Anantapur farmers (26%) expressed that temperature is another factor that influences Agriculture.
- 16% of the farmers expressed that sunshine is also an important parameter for crop production.
- Most of the farmers (54%) have seen the rain gauge and know that it is used for measuring rainfall.
- Interestingly, the farmers observed that rainfall is decreasing (71%) and summer temperatures are on the rise (86%). Winter temperatures on the other had decreasing (40%).
- Farmer's perceived that the occurrences of cyclones were decreased. Dust storms were increased (33%).
- In the Agriculture front, farmers observed that the incidence of pests/diseases was on the rise (41%).
- 60% of the farmers have changed this crops based on the climate variability. The reasons expressed that yields are not stable and not yielding due to change in weather, increased damage due to pests/diseases and extreme weather events.
- 90% of the farmers felt that higher the pesticide application, higher the harm that does to environment.
- Most of the farmers (64%) feel that conservation of natural resources and bio diversity may control the climate change. 95% of the farmers are ready to take pledge for conserving the natural resources.
- All the farmers agreed that they educated new things about weather & climate and this one day awareness program has helped them to realize about the climate change and measures need to be taken.

Climate based ITKs for Pest and Disease warning

S.No	ITK	Meaning	Crop	Source details
1	Dih-e rodh, rat-e jal, tate bare dhaner bal	If there is proper sunlight in a day or day is cloudless and if there is rainfall at night, then the strength of rice (in case of protecting insect pest and Diseases) is increased	Rice	AICRPAM, Mohanpur farmers awareness programme
2	Kuraintha veppanilai martrum athiga kartin irappatham irrunthal pugaiyan puchi athigamaga nel pairai pathikkum	Low temperature and high humidity encourages brown plant hopper incidence	Rice	S.Gangamuthu (69), Farmer, s/o Samuel, Gomathimuthupuram, Panaiyur (P.O), Sankarankovil (TK), Tirunelveli (Dt) AICRPAM, Kovilpatti
3	Paurnami nalil nel pairil karuppu vandu thakkuthal athigamaga irukkum	Rice black bug incidence is increased with full moon period time.		S.Gangamuthu (69), Farmer, s/o Samuel, Gomathimuthupuram, Panaiyur (P.O), Sankarankovil (TK), Tirunelveli (Dt) AICRPAM, Kovilpatti
4	Masi mathathil pairin muthirchi paruvatil athikamana veppam irrunthal ilamsivappu kaipul athikamaka irukkum	If high temperature prevails coincide with maturity phase of cotton crop favours pink boll worm incidence during February	Cotton	V.Mahendran (50), Farmer, s/oVelayutharaja Arulachi T.Ramanathapuram (P.O), Athuvazhi (Via) Sivagiri (TK), Tirunelveli (Dt) - 627 760. AICRPAM Kovilpatti
5	Karthikai martum Markalli mathathil kartin irrappatham athigamaga irrunthal thathupuchi thakkuthal athigamaga irukkum	If higher air humidity occurs during November – December month, leaf hopper incidence will be high.	Cotton	V.Mahendran (50), Farmer, s/oVelayutharaja Arulachi T.Ramanathapuram (P.O), Athuvazhi (Via) Sivagiri (TK), Tirunelveli (Dt) - 627 760; AICRPAM Kovilpatti
6	Magh Puse Bah Purwai Tab Sarso Ko Mahu Khai	If there is humidity during November-January, aphid infestation in oil seed crops will be high.	Oil seeds	R S Dhukia and N S Verma Proverbs related to Dryland Agriculture Honey Bee, 4(2&3):14-15, 1993
7	Phagun Mas Bah Purwai, Tah Gehu Mein Gerwa Dhai	If there is cloudy weather and more humidity in February, there will be an attack of rust disease in the crop	Crops for rust disease	R S Dhukia and N S Verma Proverbs related to Dryland Agriculture Honey Bee, 4(2&3):14-15, 1993
8	If sorghum is sown in July it will be prone to attack by shootfly		Sorghum	R S Dhukia and N S Verma Proverbs related to Dryland Agriculture Honey Bee, 4(2&3):14-15, 1993

S.No	ITK	Meaning	Crop	Source details
9	Thematho kudina nallani meghalu pantalo pacha mariyu charika purugulaki nelavulu	Rice crops harbours jassids and stem borers when there are Black clouds with moisture	Rice	Yadayya, Farmer, Jaffergudem NAIP villages, Warangal
10	Arudralo vari panta. Nindunu dhanyam inta	Rice Crop sown in arudra karthe decreases disease incidence which leads to good crop yield due to low pest incidence	Rice	B.Nagaih, Farmer, Jamisthanpur NAIP village, Mahabubnagar
11	Rohini karthe lo jonnalu, kan-dulu, amudalu chethiki andhunu panta	Sorghum red gram Crops sown under Rohini lunar contellation produce more due to low pest incidence	Sorghum, Redgram	B.Nagaih, Farmer, Jamisthanpur
12	Utthra karthelo panta purugulu talu palu		Rice	Badri Naik-kodur thanda
13	Nallani meghala tho kammu-koche varsham domapotu ku karanam	Rainfall with dark clouds leads to more hopper and jassid attack		Rani Kusumbhaithanda NAIP villages Mahabubnagar
14	Akalavarsham tho, panta chida pidalamayam	Unseasonal rainfall harbours pests and diseases in the crop	General crops	Indigenous weather & forecast practices of coimbatore district farmers of Tamilnadu. N.Anadraja, T.Rathatha Krishnana, M.Ramasubrian, P Saravanan & NS Suganthi
15		More black clouds during the win-ter season increases pest and disease incidence	General crops	Indian journal of Traditional Knowledge Vol 7(4) October 2008
16		Continuous drizzling indicates more pest & disease incidence	General crops	Indian journal of Traditional knowledge Vol 7(4) October 2008
17	*Kharif* ki purugekkuva, *rabi* ki tegulekkuva	*Kharif* paddy cultivation is more prone to pest s and rabi crop to disease attack	Rice	Nageswara Rao Nalgonda
18		Intermittent rains with rising tempera-tures increase aphid population		

INFOCROP castor model

INFOCROP castor model is further fine tuned by incorporating crop specific information such as optimum temperature, cardinal temperature, base temperature for different stages, sterility low and sterility high, Shell, No of potential grain, Grain filling rate, photosynthesis, PAR extinction coefficient. Further the model needs to be modified by generating information.

The response of important rainfed crops to elevated CO_2 levels in terms of growth and seed yield

In case of food legumes where grain is harvested for human consumption, the translation of increased biomass more towards grain or improved harvest index need to be achieved for breaking the yield barriers of these very important C3 grain legumes predominantly grown in the marginalized rainfed areas. India is the largest producer and consumer of pulses in the world. India grows pulses in about 22.5 million hectare and 80 per cent is in dry areas. However, pulses production has been stagnant at between 11 and 14 million tonnes over the last two decades. Per capita pulses consumption over the years has come down from 61gm/day in 1951 to 30 gm/day in 2008 (Amender Reddy, 2009). Elevated CO_2 condition appears to improve the overall growth of plants in general and may result in changes in partitioning of photo assimilates to various plant organs over time. An attempt was made in this research program to quantify the response of pigeon pea - a rainfed grain legume crop to increased atmospheric CO_2 level in terms of total biomass, grain yield, fodder yield and partitioning efficiency.

Pigeon pea (*Cajanus cajan*) cv ICPL 88039 an extra short duration variety showed a significant improvement in the biomass and seed yield along with enhanced HI with both elevated CO_2 levels *viz.,* 550 and 700ppm. At 700ppm CO_2 the total biomass recorded an improvement of 91%, grain yield 150%, fodder yield 67%. The major contributing components for improved grain yield under elevated CO_2 in pigeon pea were number of pods/pl and seeds/pl which recorded an increase of 97.9% and 119.5% respectively with increase in CO_2 from 370ppm to 700ppm.

To assess the response of pigeon pea to elevated CO_2 levels in terms of growth and seed yield

Extra short duration pigeon pea cv ICPL 88039 obtained from ICRISAT was evaluated for its response to two elevated CO_2 levels (550 ppm & 700 ppm) in terms of biomass and seed yield along with ambient CO_2 level (chamber control) and open field control. The crop was raised in OTCs at 700 ppm, 550 ppm and ambient CO_2 (370 ppm) levels from sowing to harvest during *kharif* 2009. During the *kharif* 2009, the crop received 566.4 mm rainfall in distributed 30 rainy days and the crop experienced prolonged dry spells during initial two months growth period (Fig.54).

The biomass accumulation and its partitioning to different plant parts were quantified by destructive sampling at regular intervals. In order to avoid mutual shading thinning was carried out and fifteen plants per OTC were maintained after 60 days after sowing. The seed yield and yield components were recorded at final harvest and presented in Table.13.

Table 13. Yield and yield components of pigeon pea (ICPL 88039) under elevated CO_2 levels - 2009 *kharif*

Parameters (per plant)	700ppm	550ppm	Ch. Control	OC
Total biomass (g)	116.9 (91)	77.5(27)	61.1	63.9
Fodder weight (g)	72.4 (74)	49.3 (19)	41.6	45.4
No. of pods	153 (98)	96 (24)	77	83
Pod dry weight (g)	62.2 (117)	40.2(40)	28.7	27.2
No. of seeds	489 (120)	313 (40)	223	206
Grain wt. (g)	44.6 (128)	28.3 (45)	19.5	18.5
100 Grain wt. (g)	8.7 (-4)	8.5 (-5)	9.0	8.5
Harvest Index (%)	38.1 (19)	36.5 (14)	32.0	29.0

Values in parenthesis are % increase over chamber control

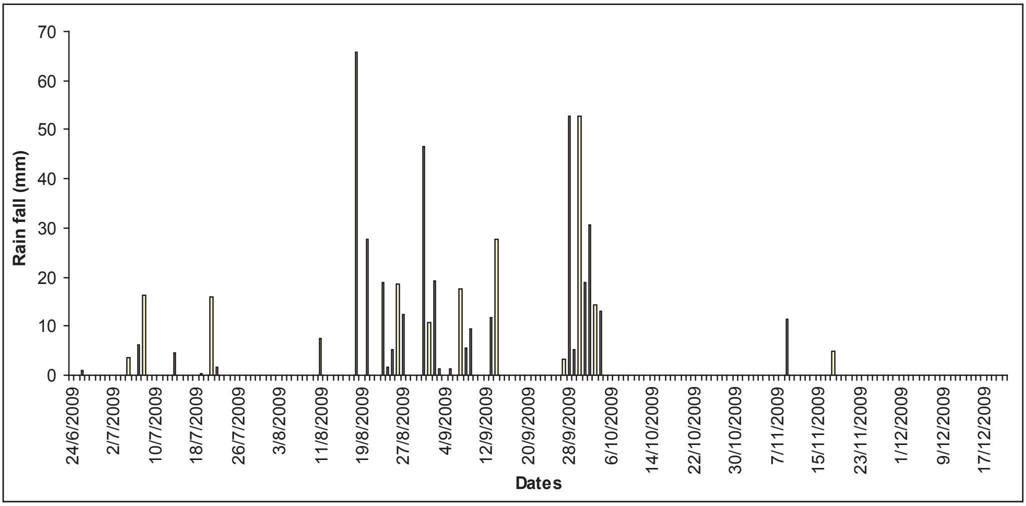


Fig.54. Rainfall received during crop growth period of pigeon pea (ICPL 88039) - 2009 *kharif*

Salient findings

Phenology

The days to initiation and 50% flowering were 47 & 63days, 52 & 62 days and 75 & 107 days for 700ppm, 550ppm and ambient chamber control respectively. Due to this early initiation of flowering under elevated CO_2 and maintaining growth for longer periods, at the end of crop growth period the number of flushes increased with increased levels of CO_2.

Leaf characters

The pigeon pea crop maintained higher leaf area under elevated CO_2 levels up to 60 days after sowing and there after the difference between CO_2 levels was not significant. The same trend was recorded for leaf dry weight with different levels of CO_2. Pigeon pea specific leaf area was not affected by increased levels of CO_2.

Root characters

The response of pigeon pea root length, root volume and root dry weight with elevated CO_2 levels was high up to 60 days after sowing and the differences was minimized there after.

Total biomass

In pigeon pea, the total biomass improved from 61.1 g/pl at ambient to 77.5 g/pl at 550ppm and 116.9 g/pl under 700ppm CO_2, there by showing an improvement of 26.8% and 91.3% at 550ppm and 700ppm respectively. At elevated CO_2 condition, the increased photosynthesis in all C3 plants result in increased plant biomass and the response of nitrogen fixing legumes is more as compared with other non leguminous C3 crops. This could be due to the unaffected leaf N levels of majority of legumes under elevated CO_2 condition.

Seed yield & fodder

The grain yield of pigeon pea cv ICPL 88038 improved from 19.5 g/pl at ambient to 28.3 g/pl and 44.6 g/pl at 550ppm and 700ppm, thereby showing an increment of 44.6% and 128.1% with enhanced CO_2 levels. The pod number per plant showed an increase of 23.8% at 550ppm and 97.9% at 700ppm over ambient chamber control which was about two fold value as that obtained at 370ppm showing it to be an important yield contributing component. The flower to pod conversion and retention of flower as well as pods in pulses is sensitive to abiotic stresses like moisture, temperature and nutritional stresses there by reduction in sink size result in reduced grain yield. In the present study it was clearly evident that the enhanced levels of CO_2 significantly improved the number of pods and seeds translating into higher grain yield.

A very high response of 40.2% at 550ppm and 119.5% at 700ppm increase in number of seed was observed with the present extra short duration pigeon pea variety ICPL 88039, over ambient control, showing more than two fold increase in the value at 700ppm revealing the character importance to yield increase as well as the character response to increased CO_2 there by impetuous on the yield contributing character is to be laid in the crop improvement program for sustaining the high yields by this important grain legume. The response of 100 seed weight under elevated CO_2 was relatively less as compared to number of pods and number of seeds implying that this character is not contributing much towards improvement in grain yield in response to elevated levels of CO_2.

The crop maintained a significant positive increase for HI at elevated CO_2 i.e. from 29.2% HI at 370ppm to 36.5% at 550ppm and 38.2 % HI at 700ppm, thus showing an increment of 14% and 19.2% over ambient values. This was the resultant of a proportionate equal increment in total biomass and also grain yield under elevated CO_2. Therefore this crop may be worth emphasizing for food sustenance with nutritional security under climate change scenario.

Impact of elevated CO_2 and temperature on host-herbivore interactions

Adaptation of insect pests under elevated CO_2 conditions

The necessity of long term experiments including more than one or two generations was emphasised. In very few cases, studies were conducted for more than one generation to evaluate the impact of elevated CO_2. Further multi generational studies are needed to understand the cumulative effects of elevated CO_2 levels at the individual and population level to develop realistic predictions of long-term population dynamics. These studies note the effects of elevated atmospheric CO_2 on leaf quality of castor *and* ground nut and study its impact on growth characteristics of leaf feeding caterpillars (*A .janata and S. litura)* over consecutive generations. These studies aimed to (i) quantify the impact of elevated CO_2 on four successive generations of both the insect pests (ii) estimate the population dynamics (potential population increase index) under elevated CO_2 conditions. Feeding trials using neonate larvae of *A. janata* on castor and *S.litura* on groundnut were performed. Castor and Groundnut were grown in three conditions, two elevated CO_2 concentrations 700±25, 550±25 ppm and ambient CO_2 (350±25ppm) in OTCs.

The impact of CO_2 concentrations and generations was significant on both the insect species (*A. janata* on castor and *S. litura* on groundnut. The increased consumption was observed over generations across CO_2 conditions (Fig1). The weight of foliage (fresh) consumed by *A.janata* on castor was significantly varied by main factor (CO_2) and sub factor (generations). The impact of elevated CO_2 ($F= 282.56$, df =2, 8, p=<0.01) and generations (F=16.08, df=3, 36, p=<0.01) was significant. The interaction between CO_2 conditions and generations was found to be not significant (F=3.34,df=6,36, p=>0.05).

- The variation of larval weights across CO_2 conditions and over generations was depicted in Fig2. Larval weights of *A.janata* fed on leaves of castor grown under elevated CO_2 conditions were not significantly varied among four successive generations (F= 2.41, df= 3, 36, p=>0.05).Significantly higher larval weights were recorded in elevated CO_2 treatment (F= 352.58, df= 2, 8, p=<0.01). The interaction between CO_2 conditions and generations with respect to larval weights was found to be not significant (F=1.04, df=6, 36, p= >0.05).
- The insect performance indices viz., approximate digestibility (AD), Efficiency of ingested food (ECI), Efficiency of digested food (ECD) and Relative growth rate (RGR) were significantly altered over generations.
- Changes in the quality of the castor and groundnut foliage effected the growth, development and food utililsation of insects. Decrease in nitrogen, water and increased carbon and C: N ratio was noticed.
- The results indicated that CO_2 levels adversely affect the quality of foliage and increased the RCR of larvae for longer period on castor and groundnut to produce less fecund adults of both species through generations.
- Significantly longer larval life span for third and fourth generations, lower pupal weight for all generations was observed under elevated CO_2 conditions. The fecundity (egg laying capacity) was also decreased for third and fourth generations.

- Similar trends were noticed with *S litura* on groundnut also in four successive generations.
- Different larval history parameters were used to estimate the Potential population dynamics during four generations of *A.janata* on Castor. After considering the data on total eggs laid by the females, potential initial number of larval individuals, the estimation of potential population index and potential population consumption index will be calculated which can serve as an indicator to estimate population dynamics of both the pests under elevated CO_2 environment (Fig. 55).

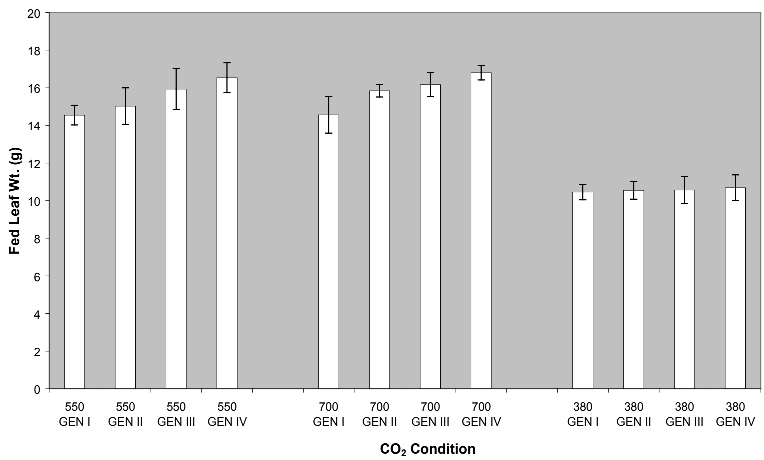


Fig.55. Fed leaf weight in four successive generations of *A. janata* in Castor, 2009-10

Impact of elevated carbon dioxide and cropping on soil organic carbon pools and nutrient status

Profile based soil samples were collected from open top chambers (OPC) with elevated CO_2 levels of 300, 550 and 700 ppm along with fallow and control (cultivated) after 4 years of intensive cropping to study the impact of intensive cropping under elevated CO_2 on soil organic carbon pools and nutrient dynamics.

Soil properties

Soils are neutral to slightly alkaline in reaction and belong to Alfisols. Soil texture is sandy loam, non-saline, non calcareous with low water retention capacity.

Impact on soil organic carbon pools

Increased carbon dioxide levels improved soil organic carbon status from 0.36 % (Fallow) to 0.55 % (700 ppm) registering 52 % increase over uncultivated fallow (Fig.56). Compared to cultivated control the increase in soil organic carbon in 700 ppm treatment was 37 %. However, the improvements in soil organic carbon content were more conspicuous at 300 ppm CO_2 and further increase in CO_2 levels at 550 ppm and 700 ppm had not resulted in soil organic carbon improvement to that extent. Profile mean (0-60 cm) soil organic carbon content increased from 0.25 % (fallow) to 0.37 % at 700 ppm CO_2.

Compared soil organic carbon, microbial biomass carbon (MBC) levels improved substantially with increase in CO_2 levels from 300 to 700 ppm (Fig.57). Uncultivated fallow showed the lowest MBC (39.1 µg/g) and cultivated control showed slightly higher MBC levels (43.4 µg/g) over control (Fig.58). Highest MBC was recorded (141.6 µg/g) with 700 ppm CO_2. In second layer of soil (10-20 cm) also the improvements in MBC levels were significant from 38.1 µg/g (fallow) to 126.4 µg/g (700 ppm). Deeper layers maintained lower MBC levels. This indicates, MBC pool of soil organic carbon is more sensitive to elevated carbon dioxide levels as compared to total organic carbon in soil.

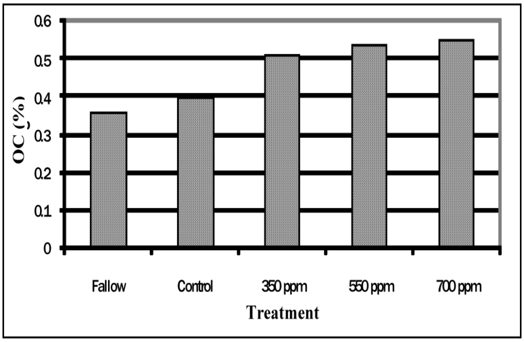


Fig.56. Impact of elevated CO2 and cropping on organic carbon in surface soil (0-10 cm)

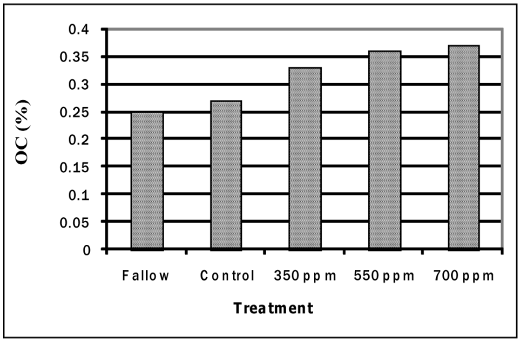


Fig.57. Impact of elevated CO2 and cropping on profile mean organic carbon content of soil

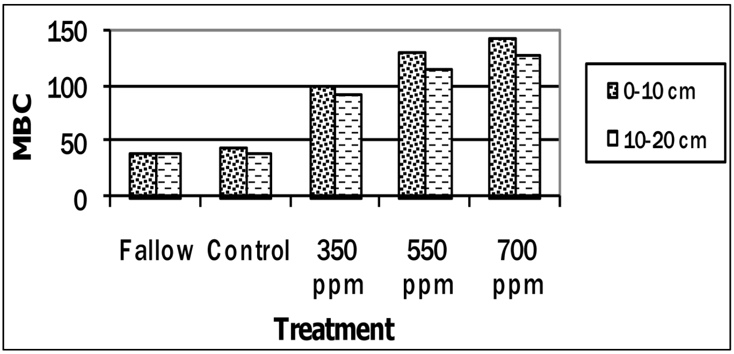


Fig.58. Impact of elevated CO_2 and cropping on microbial biomass carbon (µg / g) content in soil

Nutrient buildup and depletion in soil

Increase in carbon dioxide levels up to 700 ppm depleted soil nutrients drastically as compared to fallow and cultivated control. Available N content decreased from 210 kg/ha in cultivated to fallow to 151 kg/ha at 700 ppm CO_2 after 5 years of intensive cropping. As such most of the rainfed soils are low in available N (<280 kg/ha). With higher biomass production at elevated CO_2 levels the resulted in mining of soil nutrients such as available P from 62 kg/ha (Cultivated control) to 31 kg/ha (700 ppm), available K from 198 (fallow) to 129 kg/ha (700 ppm), available Zn from 0.71 mg/kg (fallow) to 0.34 mg/kg (700 ppm) and available Fe from 3.5 mg/kg (fallow) to 1.7 mg/kg (700 ppm) (Fig.59 to 63).

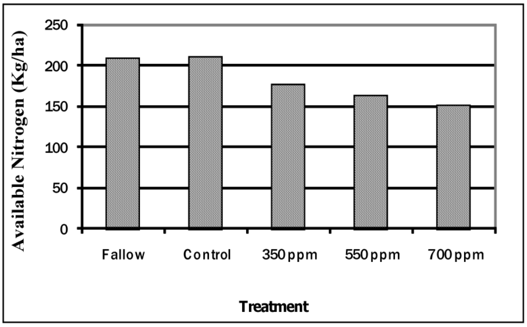


Fig.59. Impact of elevated CO2 and intensive cropping on available N content in surface soil (0-10 cm)

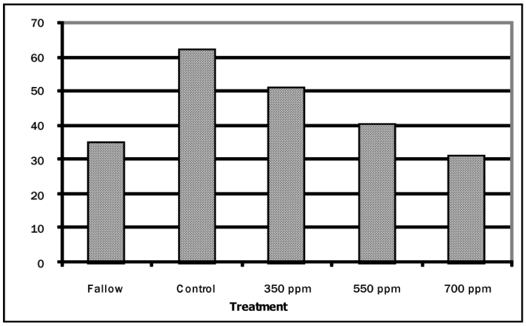


Fig.60. Impact of elevated CO2 and intensive cropping on available P status of soil (0 – 10 cm)

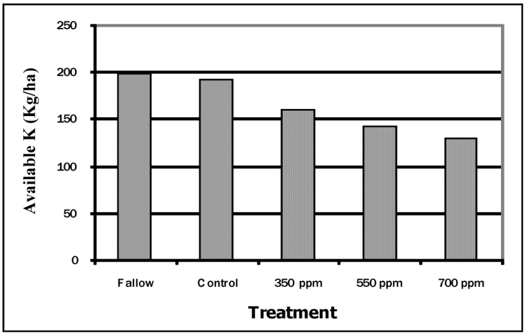


Fig.61. Impact of elevated CO2 and intensive cropping on available K status of soil (0 -10 cm)

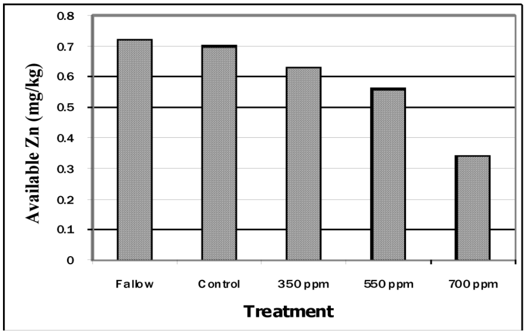


Fig.62. Impact of elevated CO2 and intensive cropping on available Zn status of soil

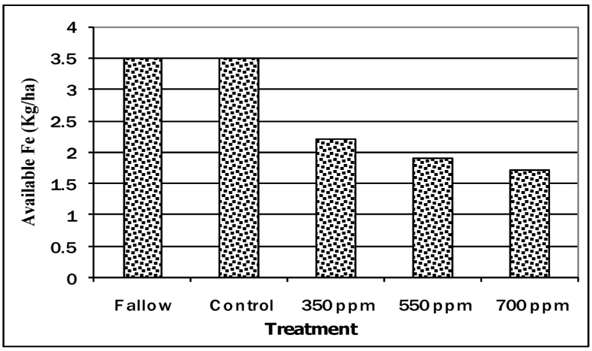


Fig.63. Impact of elevated CO2 and intensive cropping on available Fe status of soil

A specialized elevated CO_2 chamber was fabricated to expose the pathogens and biocontrol agents to higher levels of CO_2 and measure the impacts. The CO_2 levels were constantly monitored. Also a special petriplate was designed to ensure exposure of the cultures *in vitro* to desired elevated CO_2 levels. To evaluate the impact of elevated CO_2, five major soil-borne plant pathogens which have wide host range like *Rhizoctonia solani, Sclerotium rolfsii, Macrophomina phaseolina, Botrytis ricini* and *Fusarium oxysporum* f.sp. *ricini* and two popular biocontrol agents, namely *Trichoderma viride and Pseudomonas* spp. were selected.

At 700 ppm concentration of CO_2, in *R. solani*, and *S. rolfsii* more sclerotia formed after 15th generation as compared control. Preliminary observations also suggest that sporulation increased in *Trichoderma viride* under elevated CO_2, however, the growth was 15-20% slow at 15th generation when compared to the 1st generation. However, the bioefficacy of the strains in terms of competition for substrate remained unaltered up to 15th generation.

Seven strains of *Pseudomonas* spp were passed through 8 generations and an assessment of PGPR traits was made for PGPR traits like IAA production, Ammonia, siderophore, HCN production, nitrate reduction and bio-efficacy ability. The efficiency of the all the strains of *pseudomonas* are reduced under elevated CO_2. The reason could be also due to increase in temperature under elevated CO_2 conditions. In the preliminary trials, after exposure up to 30th generation to elevated CO_2 conditions, *T. viride* showed about 25% enhanced mycoparasitism against *Rhizoctonia solani and Sclerotium rolfsii,* as compared to control.

After 30 geenrations of exposure to elevated CO_2 the sporulation in *T. viride* increased considerably. Sporulation is one of the important traits for the multiplication and formulation of this fungus as a biocontrol agent. Increased sporulation also provides better fitness for the strain (Fig.64).

Control **Elevated CO_2**

Fig.64. Effect of elevated CO_2 on sporulation of *T. viride* after 30 generations of exposure

Effect of elevated CO_2 on the *in-vitro* bioefficacy of *Trichoderma* against different phytopathogens (*Macrophomina phaseolina, Fusarium oxysporum.f.sp.ricini, Rhizoctonia solani, Sclerotium rolfsii*) was observed by dual culture assay.

The results of per cent inhibition in radial growth of *M. phaseolina, F. oxysporum* f.sp. *ricini* by *Trichoderma viride* increased slightly after 10th generation whereas against *Sclerotium rolfsii*, the effect was noticed after 20th generation. The sclerotial parasitism has also been tested for *Trichoderma* and preliminary findings show that the ability of *Trichoderma* to parasitize sclerotia of *S. rolfsii* increased slightly. Confirmatory studies are in progress.

Chitinase activity

Replicates of *T.viride* from elevated CO_2 have showed clear zones, when compared with those of glass chamber ones showed increased activity of chitinase (Fig.65.)

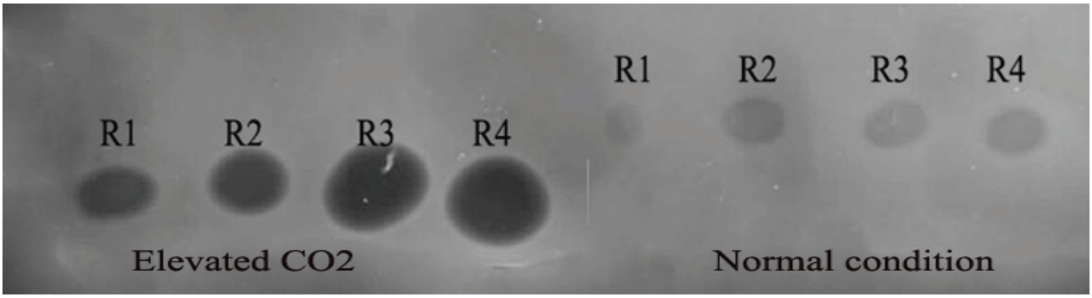


Fig.65. Estimation of chitinase by dot blot assay

Impact of elevated CO_2 on the PGPR traits of *Pseudomonas* spp

Impact of elevated CO_2 was observed on six functional properties of seven *Pseudomonas* isolates. Results showed that HCN production disappeared under elevated CO_2, in P22 isolate while nitrate production was not recorded in P35 isolate. In all the seven *Pseudomonas* isolates, IAA activity increased considerably (Table.14).

Table.14. PGPR traits of *Pseudomonas* spp at zero generation on elevated CO_2 and glass chamber

Strains	Traits									
	HCN		IAA µg/ml		Ammonia		Siderophore		Nitrate	
	G*	CO_2*	G	CO_2	G	CO_2	G	CO_2	G	CO_2
P1	-	-	35.6	35.6	+	+	-	-	+	+
P17	+	+	33.9	32.9	+	+	+	+	+	+
P22	+	-	45.2	43.2	+	+	+	+	-	-
P23	+	+	32.2	32.2	+	+	+	+	-	-
P28	+	+	39.0	39.7	+	+	+	+	-	-
P35	-	-	43.9	42.9	+	+	-	-	+	-
P67	+	+	43.8	43.8	+	+	+	+	-	-

G*: Glass chamber, CO_2*: Carbon dioxide chamber at 700 ppm

CENTRAL PLANTATION CROPS RESEARCH INSTITUTE
KASARAGOD

Crop adaptation to elevated CO_2 and temperature and cultivar/hybrid most suitable for climate change conditions

Objective: Study the effect of elevated temperature and CO_2 on response of coconut, arecanut and cocoa seedlings

Seedlings of coconut (2 hybrids and 3 cultivars), arecanut (5 cultivars) and cocoa (3 hybrids and 4 cultivars) are being grown in Open Top Chamber facility which is having SCADA controlled pumping and monitoring of CO_2 to set level of 550 and 700 ppm and hot air for elevated temperature (set at +2 ^oC). These seedlings were provided different levels of nutrients for past 1 year. Several morphological, anatomical, physiological and biochemical parameters were recorded at 4 monthly interval. Some of the mean results are presented in this section.

Results indicate that providing additional fertilizer dose improved the photosynthetic rate in coconut, areca nut and cocoa seedlings grown under elevated CO_2 and temperature regimes (Fig. 66-68). This increase in net photosynthetic rate translated into higher seedling vigour as indicated by improved seedling girth at collar in coconut seedlings (Table 15). This experiment is under progress.

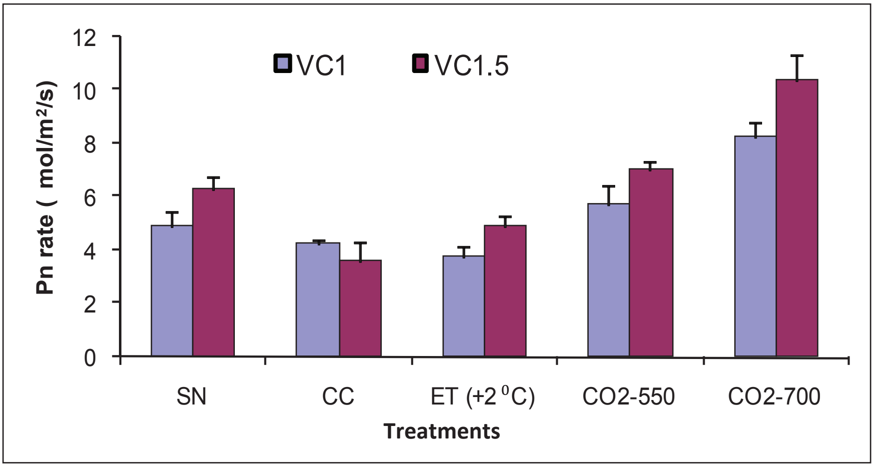


Fig.66. Change in Pn rate in coconut seedlings grown in elevated CO_2 and temperature conditions and provided with different nutrient quantities

Table.15. Collar girth in coconut seedlings grown in elevated CO_2 and temperature conditions and provided with different nutrient quantities

Nutrient level	Chamber control	Elevated temperature (+2^{o}C)	[CO_2] 550 ppm	[CO_2] 700 ppm
Currently recommended	19.4	22.1	19.9	29.6
50% more than currently recommended	26.3	23.4	29.8	40.9

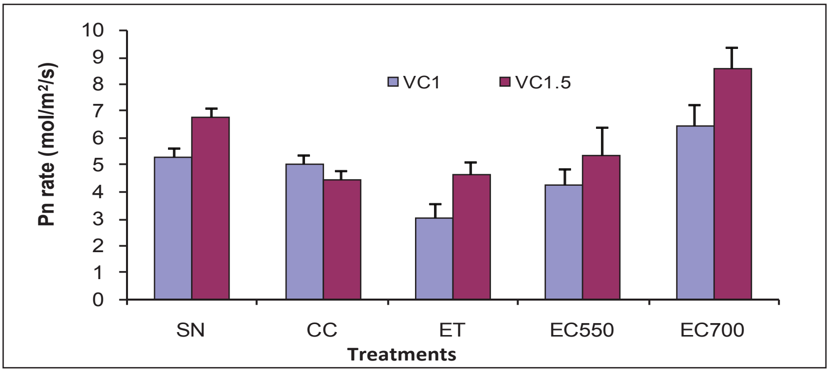


Fig.67. Change in Pn rate in arecanut seedlings grown in elevated CO_2 and temperature conditions and provided with different nutrient quantities

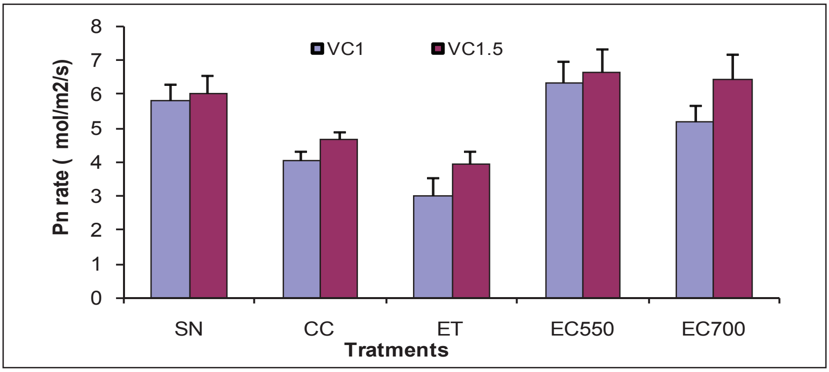


Fig.68. Change in Pn rate in cocoa seedlings grown in elevated CO_2 and temperature conditions and provided with different nutrient quantities

The coconut seedlings were also provided with differential irrigation and results indicate that life saving irrigation reduced photosynthetic rates in elevated temperature condition. However, in elevated CO_2 conditions photosynthetic rates were higher even in seedlings receiving life saving irrigation. Reduction in net photosynthetic rates due to delayed irrigation on life saving irrigation was found to be more under elevated CO_2 conditions (Fig. 69).

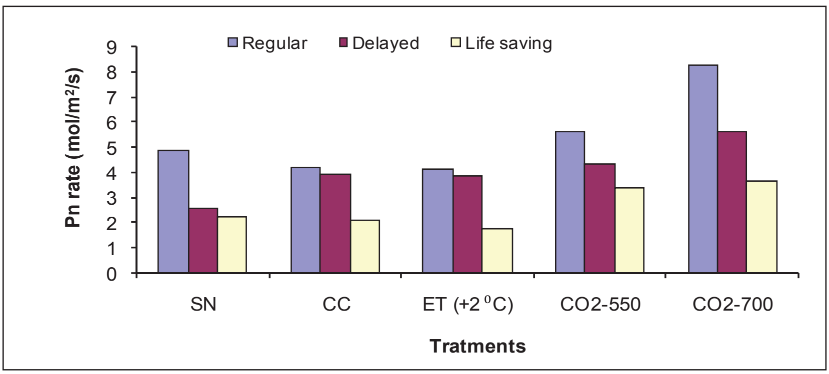


Fig.69. Change in Pn rate in coconut seedlings grown in elevated CO_2 and temperature conditions and provided with differential irrigation

Adaptation strategies for coconut plantations to climate change scenarios in different agro-climatic zones

Objective: Study the suitability of measures of adaptation in coconut plantations to climate change in different agro-climatic zones using simulation model

In plantation crops, management of crop becomes very important during adverse conditions in order to sustain the productivity. Since a standing plantation crop will face the climate change and variability effects during their life period due to perennial nature, the following strategies may be adapted to reduce the adverse impacts of climate change and also to maximize the positive effects of climate change. These adaptation strategies are derived from evidences drawn from extensive experiments.

Simulation analysis on adaptation strategies for coconut plantations

Simulation analysis indicated that negative impacts of climate change can be overcome by adaptation strategies such as assured irrigation through drip system coupled with soil moisture conservation and by providing fertilizers / nutrients through organic and inorganic source in doses higher than those currently applied by the farmers. Such measures also maximize the positive impacts of climate change.

State-wise projections on adaptation strategies and respective gains in production are presented in Table 16. Data indicate substantial gains obtainable by adapting to climate change. In Kerala, providing more fertilizers along with summer time irrigation coupled with soil moisture conservation can further improve the positive gains due to climate change by 7 to 21% in different scenarios.

Table 16. Projected gains in coconut production (% deviation from current yields) due to differential adaptation to climate change

STATE	Adaptation Strategy	Adaptation gains (%)			
		A1b 2030	A1b 2080	A2 2080	B2 2080
Andhra Pradesh	Intensive management	31.3	56.7	47.5	33.8
Karnataka	Assured irrigation and improved fertilizers	22.1	31.3	29.9	27.1
Kerala	Medium irrigation with improved fertilizers	21.0	12.2	7.4	13.5
Tamil Nadu	Intensive management	29.7	34.3	32.8	38.5

These adaptation strategies are designed keeping in view of the differential management levels prevalent among the states and among the plantations with in a state.

In Karnataka, West Bengal, Gujarat, Maharashtra and Orissa assured irrigation and providing more fertilizers can not only off-set the negative impacts but can result in higher yields. Adaptation gains in these states ranged from 2-40% in different scenarios. In order to offset the negative impacts of climate change in Andhra Pradesh and Tamil Nadu, intensive management of plantations is needed. This includes planting of improved and tolerant varieties as well. In North-Eastern states, providing summer irrigation and even low dose of fertilizers can further improve (in the range of 10-33%) the positive impacts of climate change. Similarly, coconut plantations in islands, if managed scientifically –by proper spacing or by canopy management- and by providing summer irrigation and even low dose of fertilizers, positive impacts of climate change can be improved by 2-25%.

Impacts on quality of post harvest produce

Objective: Study the impact of elevated temperatures on quality of harvested products (cocoa beans, coconut copra and oil and arecanut)

Influence of storage temperature on keeping quality of arecanut was studied in the context of projected increase in temperature due to climate change. The samples were exposed to different temperatures for 2 months. Periodical observations were taken on quality aspects.

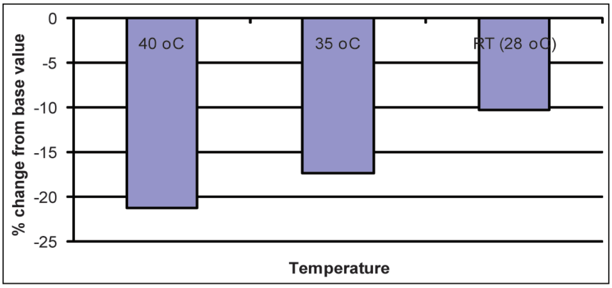


Fig.70. Myristic acid percentage as influenced by the storage temperature (Percent change from initial value after two months of storage)

Results indicated a significant reduction in myristic acid concentration in areca nut due to increase in storage temperature (Fig. 70).

Carbon trade potential of new coconut plantations as mitigation option

Objective: Study the carbon sequestration potential and stocks of coconut systems using simulation model

The carbon sequestration potential of coconut plantations was assessed using real time estimates and InfoCrop-Coconut simulation models. The outputs were up-scaled to state level. Such estimations were carried out for four major coconut growing states *viz.,* Kerala, Tamil Nadu, Karnataka and Andhra Pradesh (Fig. 71).

Simulation results indicated that the carbon sequestered in stem in coconut plantations in four states *viz.,* Kerala, Karnataka, Tamil Nadu and Andhra Pradesh is likely to be influenced by climate change. In states like AP and Tamil Nadu, the sequestration is projected to reduce by about 10 and 31%, respectively in PRECIS A1B 2030 scenario. However, in Karnataka and Kerala climate change is projected to increase the C sequestration into stem by about 28% and 3%, respectively. At all India basis also, the C sequestration is projected to increase by about 1% in 2030 A1b scenario. Further work is in progress.

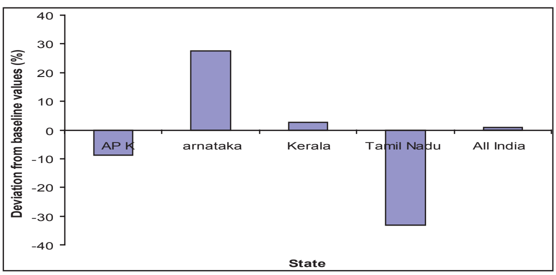


Fig.71. Change in carbon sequestration in coconut stem due to climate change in PRECIS A1b 2030 scenario

INDIAN INSTITUTE OF HORTICULTURAL RESEARCH
BANGALORE

Objective: Enhanced awareness of the farmers about climate change and its impact on horticultural crops

Farmers' Awareness Programme on Impact of Climate Change on Horticultural Crops

A farmer's awareness programme on the Impact of Climate Change on Horticultural Crops was organised on 9th December 2009 under the ICAR Network Project on Impact, Adaptation and Vulnerability of Indian Agriculture to Climate Change. About 150 farmers from Kolar, Chickkaballapur, Doddaballapur, Malur, Nanjanagud and Bangalore North taluk participated in the programme. The farmers' meet was inaugurated by Dr. K. Narayana Gowda, Dean (Agriculture), UAS, GKVK, Bangalore. The programme was presided over by Dr. M. Edward Raja, In-charge Director, IIHR, Bangalore. Dr. N.K. Srinivasa Rao, Principal Investigator of the Network Project gave a brief introduction about climate change and horticultural crops. An extension folder entitled "Climate change and its impact on horticulture" and its Kannada version was also released during the occasion. Dr. K. Narayana Gowda, chief guest, in his remarks emphasized the importance of the Farmers' Awareness Programme on Climate Change at a time when various countries were discussing the issues of climate change at International level in Copenhagen, Denmark. He emphasised the need to adapt technologies, which could help in alleviating the adverse impacts of climate change. With his personal involvement in a community development programme he stressed up on the role of fruit trees like Jackfruit, Bael and Jamoon, which not only help in reducing the levels of carbon dioxide in the atmosphere but also are remunerative to the farmers. He emphasised on the involvement of farmers' groups in dissipation of technologies to be adapted to overcome the adverse effects of climate change.

Objective: Calibrated and validated InfoCrop models for onion and tomato

i) Calibration of the models with the experimental data.

ii) Validation of the models for different agro-ecological regions, seasons, nitrogen and irrigation levels using published literature.

iii) Studies on photosynthetic response to elevated CO_2 levels and water stress and determining the threshold values in tomato and onion

Calibration of the INFOCROP model for onion was done using the data obtained from field experiments conducted at IIHR, Bangalore during 2008-09 and also from published literature. Validation of the model was taken up for different seasons, nitrogen and irrigation levels using the published literature for different agro-ecological regions (Table 17).

Table 17. Validation of the model for onion in different locations

Location	Year / Season / Date of transplanting	Treatments	Days to Bulb initiation		Days to Maturity		Yield (t/ha)	
			S	O	S	O	S	O
Dharwad	1988 / *Kharif* / 15th July	Nitrogen (Kg/ha)						
		75	48	50	117	120	17.66	20.68
		125	48	50	119	120	22.22	22.66
		175	48	50	121	120	26.42	24.19
Dharwad	1999 / *Kharif* / 20th June		45	50	119	132	20.91	20.96
Dharwad	2002 / *Rabi* / 19th Nov	I1	45	45	115	111	12.25	12.10
		I2	47	45	115	111	12.56	13.86
		I3	47	45	117	111	13.12	15.75
		I4	49	45	118	111	14.68	18.72
Hyderabad	1994-95 / *Rabi* 2nd December	Nitrogen	-	-	133	128		
		0					12.84	9.92
		50					16.50	16.72
		100					22.26	21.00
		150					26.75	23.37
		200					29.86	25.78
Karnal	1991 / *Rabi* / 15th December		-	-	128	137	23.25	30.08
Hisar	1982 / *Rabi* / 15th January	Nitrogen 150	72	68	140	135	24.10	32.68

S= Simulated; O=Observed

Though model is simulating the days to bulb initiation, days to maturity and yield levels for Dharwad and Hyderabad locations, the yield level predictions are low for Karnal and Hisar locations where onion in grown mainly in *rabi* season. Further calibration and validation of the model is required for its utility in the impact assessment studies. Daily weather data has been extracted for analysis from the scenarios generated at Indian Institute of Tropical Meteorology, Pune using Met Office Hadley Center regional climate model PRECIS provided by NATCOM funded under the MoEF. The data for both daily and monthly basis has been extracted for baseline and 2080 for the A2 and B2 scenarios and 2050 and 2080 for A1B scenarios. After further calibration of the model impact assessment under different scenarios for major growing areas would be completed.

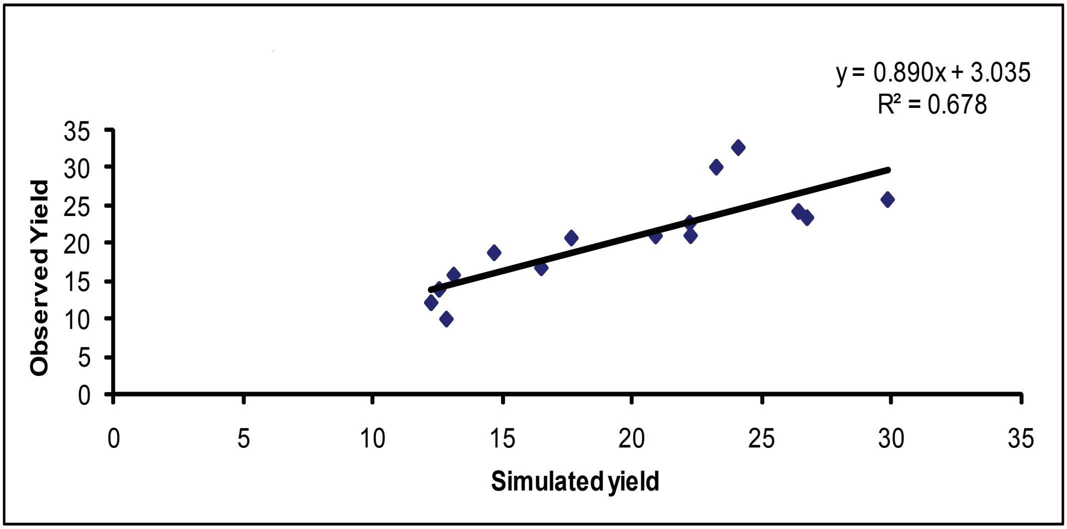


Fig.72. Model simulated yields against the observed yields of onion in different locations

An experiment was conducted in open top chambers at 550 ppm elevated CO_2 using two onion cultivars Arka Kalyan and Agrifound Dark Red (ADR) to quantify the impact of water stress on photosynthesis rate. Before stress imposition ADR recorded relatively higher photosynthesis rate (14.77 µ mol m^{-2} s^{-1}) as compared to Arka Kalyan (13.63 µ mol m^{-2} s^{-1}) (Table 18). After imposition of water stress for seventeen days, again ADR recorded higher photosynthesis rate though there was a drastic reduction of 70.73% and 82.12% in ADR and Arka Kalyan, respectively in relation to non-stressed plants. After the recovery for 22 days the plants had attained normal photosynthesis rates.

Table 18. Photosynthetic response of cultivars Arka Kalyan and Agrifound Dark Red to water stress under elevated CO_2 (550 ppm)

Cultivars	Before stress impo-sition	17 days after stress imposition			22 days after stress release		
			Arka Kalyan	Agrifound Dark Red		Arka Kalyan	Agrifound Dark Red
Arka Kalyan	13.63	Stress	1.97	3.60	Control	4.40	7.93
Agrifound Dark Red	14.77	Control	11.00	12.30	Recovered	4.63	9.77

Objective: Assessed impact of climate change on onion and tomato for the major growing regions

After further calibration of the model impact assessment under different scenarios for major growing areas would be completed.

Objective 5: Extent of impact of flooding and water stress on growth and yield of onion and tomato

i) Studies on the impact of flooding and water stress and determining the threshold values at critical stages of crop growth in onion and tomato**.**

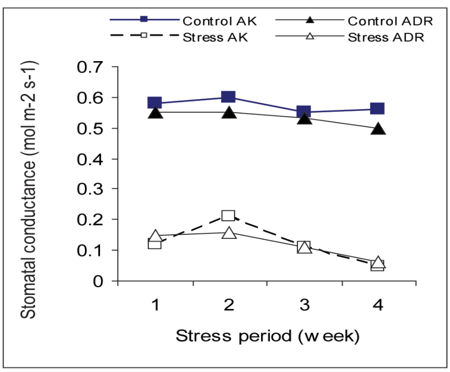
ii) Quantification of the extent of impact of flooding and water stress on growth, quality and yield.

iii) Working out the additional yield advantage due to adaptation strategies for alleviating flooding and water stress.

A study was conducted to determine the effect of water stress and flooding on plant performance and plant yield in onion (cvs. Arka Kalyan, Agrifound Dark Red) and tomato (cv. Arka Ashish).

Water stress:

Onion: Four weeks old seedlings of two varieties i.e. Arka Kalyan and Agrifound Dark Red (ADR) were planted in the field. The water stress in the field was imposed for a period of one, two, three and four weeks period. The soil moisture was 22.0% at 0 day, 13.0% at one week stress, 9.5% two week stress, 6.5%, three week stress and 5.5% at four week stress. There was substantial decrease in leaf area, root length, bulb fresh and dry mass and bulb yield under stress (Table 19). The reduction in leaf area was more than 40.0% after two weeks stress and it decreased to 53.0% at four week stress. Root growth was affected in both the cultivars but the affect was more in ADR as indicated by 44 – 63.0% reduction compared to Arka Kalyan which had a reduction of 29.0 – 53.0% under stress. The decrease in root growth was more after 3 week stress in both cultivars. There was a greater reduction in photosynthetic rate (84.0 – 92.0%), total plant dry matter accumulation (32.0 – 45.2%) and bulb dry matter (44.4 – 54.0%) after three weeks stress (Table.19 and Fig. 73) in both cultivars but the percent decrease was more in ADR than Arka Kalyan. The results indicated that the reduction in these physiological parameters under different duration resulted in a reduction in bulb size.The bulb yield reduction was higher in ADR (49.0%) compared to Arka Kalyan (34.0%) at four week stress (Table 20). The results showed that the soil moisture of 5.5% was found to be critical as it affected the physiological parameters and the bulb yield. The cultivar Arka Kalyan performed better than ADR under stress.



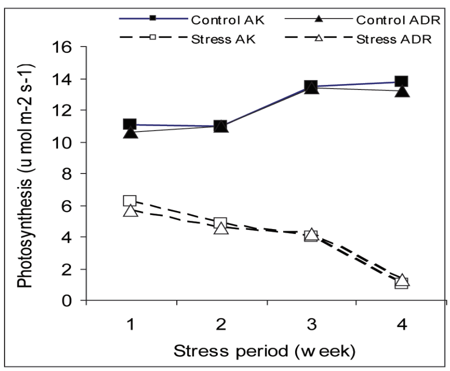


Fig 73. Response of photosynthesis and stomatal conductance in onion under water stress

Table 19. Leaf area, Root length, bulb fresh weight, bulb dry weight and total plant dry weight of onion as affected by different water stress duration

Stress duration (week)	Treatment	RWC	Leaf area	Root length	Bulb fresh wt.	Bulb dry wt.	Total dry wt.
Arka Kalyan							
One	Control	78.7	948.5	14.5	42.8	3.97	11.46
	Stress	68.3	804.5	10.3	27.4	3.12	9.91
Two	Control	78.0	1093.1	12.2	69.5	5.84	15.36
	Stress	65.0	938.4	7.8	39.0	4.44	12.02
Three	Control	79.6	1072.4	14.3	85.8	9.49	19.28
	Stress	64.1	853.0	8.3	66.9	7.32	12.89
Four	Control	78.5	1609.7	14.0	127.6	14.06	27.95
	Stress	61.7	772.7	7.3	90.1	9.58	15.47
Agrifound Dark Red							
One	Control	76.5	992.6	15.3	33.5	3.33	10.20
	Stress	72.1	913.5	8.5	26.4	2.77	9.93
Two	Control	76.5	1438.1	14.8	49.1	4.80	15.10
	Stress	68.6	838.6	6.5	38.1	3.21	10.16
Three	Control	78.2	1516.5	12.0	89.7	12.37	18.14
	Stress	66.5	838.2	5.0	71.0	7.88	11.50
Four	Control	78.3	1967.3	11.0	156.1	16.39	31.82
	Stress	64.2	922.6	4.2	84.3	8.78	14.68

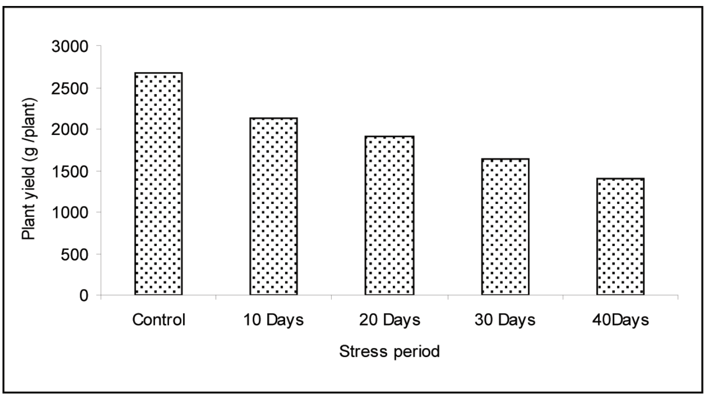
Table 20. Soil moisture (%) and plant yield (g plant^{-1}) of onion as affected by different water stress durations

Cultivar	Control	One week stress	Two week stress	Three week stress	Four week stress
Soil moisture (%)	22.0	13.0	9.5	6.2	5.5
Arka Kalyan	111	108.4	97.3	96.1	73.0
Agrifound Dark Red	132	130.0	104.0	90.0	67.6

Tomato: Seedlings (four weeks old) of cv. Arka Ashish were transplanted in the field with 50cm plant to plant spacing during *rabi* season. Plants were regularly irrigated with drip irrigation. Water stress was imposed at flowering stage by withholding the irrigation for different time periods (10 days, 20 days, 30 days and 40 days). The different water stress duration affected leaf area production, root length, flower and fruit number set and total dry matter accumulation (Table 21 and Table 22). More than 50% reduction was found in leaf area and, photosynthesis, total dry matter accumulation after 30 days stress which has the soil moisture of 6.5%. The soil moisture level, leaf osmotic potential and relative water content (RWC) decreased after 30 days stress. The reduction in the morpho-physiological parameters under different duration of stress resulted in a greater reduction in plant yield after 30 days (39.0 – 48.0%) where the soil moisture level was below 7.0%. This indicate that the soil moisture of less than 7.0% affects the physiological parameters to a greater level and resulted in a considerable decrease in yield per plant. This can be considered as critical thresh hold value of moisture content which affects the plant performance in tomato.

Table 21. Morpho-physiological parameters as affected under different stress durations in tomato (cv. Arka Ashish)

Parameters	Treatments	Stress period (days)			
		10	20	30	40
Leaf area (cm)	Control	10564.0	13214.0	12761.4	10910.3
	Stress	5354.0	7672.6	4485.8	3901.8
Root length (cm)	Control	27.3	38.3	39.7	39.8
	Stress	27.0	32.3	31.0	28.3
Flower No.	Control	117.7	175.3	76.7	0.00
	Stress	63.3	77.3	38.0	0.00
Fruit No.	Control	20.3	61.0	133.0	98.7
	Stress	20.3	31.7	52.7	49.3
Total dry wt. (g $plant^{-1}$)	Control	95.26	131.81	196.38	342.33
	Stress	56.26	83.86	80.63	152.38



Plant yield as affected by water stress in tomato

Table 22. Effect of water stress on soil moisture content, relative water content, photosynthesis rate, stomatal conductance and transpiration rate in tomato

Parameters	Treatments	Stress duration (days)			
		10	20	30	40
Soil moisture (%)	Control	19.0	19.0	18.5	18.5
	Stress	10.0	7.3	6.8	6.5
Osmotic potential (-MPa)	Control	- 0.79	- 0.79	- 0.78	- 0.79
	Stress	- 0.99	- 1.15	- 1.29	- 1.55
Relative water content (%)	Control	88.0	88.0	87.0	86.0
	Stress	82.4	82.2	80.0	79.7
Photosynthesis (μmol $m^{-2}s^{-1}$)	Control	18.8	17.2	18.7	18.3
	Stress	12.8	9.4	8.4	5.3
Transpiration (μmol $m^{-2}s^{-1}$)	Control	8.7	8.7	7.6	6.5
	Stress	7.8	5.6	5.4	4.5
Stomatal conductance (μmol $m^{-2}s^{-1}$)	Control	0.83	0.69	0.65	0.71
	Stress	0.61	0.59	0.28	0.12

Flooding:

Onion:

A study on impact of flooding on two cultivars of onion i.e. Arka Kalyan and Agrifound Dark Red was conducted during *kharif* season. Four weeks old seedlings were transplant in channel and raised beds in the field. The flooding was imposed for 2, 4 and 6 days at bulb initiation stage (55 DAP). The photosynthesis reduced at 6 days flooding. In the plants grown in raised beds the photosynthetic rate was 6.0 - 16.0% higher than the plants grown in channel at 6 days flooding (Table 23). The stomatal conductance and transpiration rate were also affected at 6 days flooding. Bulb dry matter, total dry matter and bulb yield were affected by different durations of flooding and the effect was greater at 6 days flooding (Table 24) in onion cultivars. The bulb dry matter (2.21 – 3.00 g/plant) and bulb yield (30.14 – 36.00 g/plant) were higher in the raised beds as compared to the bulb dry weight (4.06 – 5.34 g/plant) and bulb yield (45.14 – 58.3 g/plant) in the plants grown in the channel, indicating better plant growth in raised beds. The 6 days flooding was found to be critical at bulb initiation stage (55 DAP). Cultivar ADR was affected more compared to Arka Kalyan under flooding. There was a decrease in anthocynin and FRAP (ferric reducing antioxidant potential) and increase in total flavnoids in the bulbs received flooding in channel, while in the bulb growing in bunds no particular trend was observed. The total flavnoids was higher in the flooded bubs than the control. The raised bed cultivation of onion may be adopted in flood prone areas.

Table 23. Gas exchange rate and stomatal conductance as affected by flooding in two cultivars of onion

Cultivar	Flooding period		Channel			Raised bed		
			Pn (µ mole m^{-2} s^{-1})	gs (mole m^{-2} s^{-1})	E (mole m^{-2} s^{-1})	Pn (µ mole m^{-2} s^{-1})	gs (mole m^{-2} s^{-1})	E (mole m^{-2} s^{-1})
Arka Kalyan	2 days	Control	9.1	0.95	10.6	10.0	0.94	11.8
		Flooding	9.0	0.99	9.6	9.5	0.82	9.0
	4 days	Control	10.6	0.51	11.1	11.0	0.90	11.8
		Flooding	9.2	0.26	9.7	10.2	0.68	9.8
	6 days	Control	9.0	0.73	11.4	10.5	0.78	11.3
		Flooding	6.4	0.61	9.7	7.6	0.68	10.0
Agrifound Dark Red	2 days	Control	10.5	0.92	10.3	11.2	0.96	10.8
		Flooding	8.5	0.86	9.3	9.2	0.95	9.5
	4 days	Control	10.5	0.75	11.1	11.2	0.76	11.2
		Flooding	6.3	0.68	9.7	10.1	0.60	10.1
	6 days	Control	10.0	0.75	11.2	11.5	0.80	11.5
		Flooding	4.8	0.50	10.0	5.1	0.76	10.2

Pn: Photosynthesis, gs: Stomatal conductance and E: Transpiration

Table 24. Effect of different durations of flooding on bulb yield and bulb dry matter and total plant dry matter

Cultivar	Flooding duration (days)	Channel			Raised bed		
		Bulb yield wt. (g/plant)	Bulb dry wt. (g/plant)	Total plant dry wt. (g/plant)	Bulb yield (g/plant)	Bulb dry wt. (g/plant)	Total plant dry wt. (g/plant)
Arka Kalyan	Control	44.14	4.55	5.49	91.74	9.73	12.34
	2day	40.88	3.95	4.80	84.98	9.34	11.1
	4day	37.82	3.69	4.62	71.33	7.43	8.88
	6 days	36.00	3.00	4.41	58.30	5.34	6.86
Agrifound Dark Red	Control	42.52	4.00	5.39	65.57	6.28	8.73
	2day	33.21	2.49	4.00	65.57	6.48	8.34
	4day	33.0	2.73	4.16	55.14	4.76	7.37
	6days	30.14	2.21	4.68	45.14	4.06	6.53

Tomato: The seedlings of tomato cv Arka Ashish were transplanted in the channel and the raised beds with a spacing of 50.0cm plant to plant. Plants were subjected to flooding at flowering and fruiting stages for 6, 12, 24 and 48 h duration. The reduction in photosynthetic rate was 42.0% at 24 h flooding and 58.3% at 48 h flooding in channel, while in raised bed it decreased to 27.0% at 24 h flooding and 46.0% at 48 h flooding (Table 25). After releasing flooding (30 days after releasing) the leaf senescence increased and it was higher in the channel (43.0 – 60.0% in flowering and 46.9 – 76.8 % in fruiting) than the plants growing in raised beds (42.5 – 51.6% in flowering and 40.3 – 74.5% in fruiting). The leaf senescence was greater in fruiting stage than flowering stage (Table 26). The marketable yield was more in the raised beds as compared to the channel at both the stage under flooding. The effect of flooding was higher after 24 h as indicated by the reduction in yield and other parameters indicating the greater effect of flooding after 24 h. Flowering stage was found to be critical to flooding compared to fruiting stage and the plants performed better under raised under flooding (Table 27).

Table 25. Net photosynthesis (Pn, µmol m^{-2} s^{-1}), stomatal conductance (sg, µmol m^{-2} s^{-1}) and transpiration (µmol m^{-2} s^{-1}) as affected by different duration of flooding at flowering stage

Duration		Channel				Raised beds			
		Pn	sg	AE	Ci	Pn	sg	AE	Ci
6hr	Flooding	15.0	0.86	13.0		15.8	0.88	11	270
	Control	15.8	0.88	13.5	275	16.0	0.88	12.0	278
12hr	Flooding	14.0	0.75	13.0	280	15.5	0.74	10.5	275
	Control	15.0	0.85	13.5	272	16.0	0.85	12.5	280
24hr	Flooding	9.0	0.65	8.5	289	11.4	0.66	9.4	285
	Control	15.5	0.80	13.4	275	15.6	0.80	12.8	260
48hr	Flooding	6.5	0.54	8.0	295	8.0	0.54	9.0	288
	Control	15.6	0.76	11.0	270	15.0	0.76	11.5	275
96hr	Flooding	4.0	0.46	6.9	299	5.9	0.63	7.8	290
	Control	15.2	0.76	10.0	269	16.0	0.76	10.6	270

Table 26. Leaf senescence (%) 45 days after releasing the flooding in tomato grown in channel and raised beds

Flooding duration	Flowering		Fruiting	
	Channel	Raised beds	Channel	Raised beds
6 hr	43.0	42.5	46.9	40.3
12 hr	52.9	43.1	64.0	57.2
24 hr	57.6	50.0	72.0	70.2
48 hr	60.0	51.6	76.8	74.5

Table 27. Plant yield (g plant-1) as affected by flooding in tomato

Flooding duration	Flowering stage		Fruiting stage	
	Channel	Raised beds	Channel	Raised beds
6 hr	2000	2200	2250	2500
12 hr	1800	1800	2000	2300
24 hr	1400	1750	1850	2100
48 hr	1100	1650	1720	1850

Objective: Assessed impact of climate change under different scenarios on fruit quality and phenology of wine grapes

i) Extraction of data on weather parameters for different climate change scenarios.

ii) Linking fruit quality with changes in temperature under different climate change scenarios for major grape growing regions.

The scenarios generated at Indian Institute of Tropical Meteorology, Pune using Met Office Hadley Center regional climate model PRECIS were used for the extraction of monthly data for baseline and 2080 for the A2 and B2 and 2050 and 2080 for A1B scenarios.

Grapes in two major wine grape growing regions under study, Nasik and Bangalore do not undergo dormancy and remain evergreen throughout the year. The annual growth cycle of the vines is manipulated in accordance with the prevailing climatic conditions. In both the regions grapes are grown by practicing double pruning and single cropping system and three to four months of dry period is essential to mature the fruits without affecting berry quality. Rainfall during the months of February to April is very crucial, as berries mature during this period and rainfall above 10 mm would affect the quality. In Nasik region rainfall is mainly received during the months of June to September and in Bangalore region during May to November. Thereafter it is relatively dry and occurrence of rain during berry ripening is very rare which enables production of good quality grapes. The analysis of rainfall patterns during the grape growing season for the extracted scenarios with respect to baseline for two major wine grape growing regions was taken up. It is observed that in A1B 2050 and 2080 scenarios there is an average increase in rainfall of 11.11% and 18.98% with respect to baseline average. Whereas in A2 2080 scenario there is an increase of 81.74% during the fruit maturation period. When rainfall is considered in terms of millimetres during fruit maturity it is low and would not affect fruit quality. Hence, in A1B 2050, 2080 and A2 2080 scenarios there would not be much influence of rainfall on berry quality due to slight increase in rainfall during berry maturation phase, February to April. However only in A2 2080 scenario rainfall during the month of October would increase the incidence of Downey mildew disease on leaves and flower clusters.

Table 28. The observed average monthly rainfall, maximum and minimum temperatures of the baseline period (1960-1990) during the grape growing season in Bangalore and Nasik

Months	Bangalore				Nasik			
	Rainfall (mm)	T Max (ºC)	T Min (ºC)	Cumulative average	Rainfall (mm)	T Max (ºC)	T Min (ºC)	Cumulative average
October	142.18	27.7	19.4	23.5	46.11	32.23	18.04	22.5
November	60.93	26.7	17.4	22.8	25.10	30.58	14.42	23.8
December	21.94	25.9	15.9	22.2	5.32	28.67	12.30	22.7
January	1.08	26.5	14.9	21.8	1.58	29.12	11.44	22.1
February	7.70	29.3	16.4	22.0	0.21	31.22	12.95	22.1
March	15.05	32.5	19.4	22.7	0.94	34.87	17.18	22.8
April	33.93	33.9	21.8	23.4	2.63	37.66	21.06	23.7
Mean	282.82	28.9	17.9		81.89	32.05	15.34	

The temperature has greater bearing on wine grape quality. Growing season temperatures are a measure of the ripening potential for grape varieties grown in different regions. The two wine grape cultivars, Cabernet Sauvignon and Shiraz based on relationship between phenological requirement and climate for production of quality wine in the world, are grown in regions that span from intermediate to hot climates. The average growing season temperatures range from roughly 16.5 to 19.5 ºC. Whereas, when the average growing season temperatures for Bangalore and Nasik regions are considered from October to March, 22.7 and 22.8 ºC, respectively or latest by April 23.4 and 23.7 ºC, respectively these varieties are already grown under high temperatures (Table 28).

Table 29. Average increase in temperatures during grape growing season for Bangalore and Nasik regions under different scenarios with respect to baseline

Scenarios	Bangalore			Nasik		
	T max ºC	T min ºC	Average	T max ºC	T min ºC	Average
A1B 2050	2.53	2.39	2.46	2.82	2.85	2.84
A1B 2080	4.45	5.09	4.77	4.25	5.00	4.63
A2 2080	2.41	3.67	3.04	3.37	3.95	3.66
B2 2080	2.33	2.63	2.48	2.40	2.82	2.61

The extracted monthly data for the scenarios A2 and B2 2080 and A1B 2050 and 2080 was analysed and average growing season temperatures were compared. In 2050 A1B scenario the increase in average temperature for Bangalore and Nasik regions are 2.46 and 2.84 ºC and in B2 2080 scenario 2.48 and 2.61ºC, respectively are expected (Table 29). And the temperature increases are expected to be still higher in A2 2080 and A1B 2080 scenarios. The berry skin accumulates large amounts of anthocyanin, fruit juice include sugars, acids, tannins, flavanoids and other chemicals, that are produced as the berries ripen. The proportion of these substances greatly depends on weather and growing season. Based on the correlation analysis of the quality parameters of the fruits collected last year at different growing temperatures the decrease in contents of the major components is presented in table 30. The contents in Shiraz are much more affected than Cabernet Sauvignon, indicating its vulnerability to increases in temperature.

Table 30. Decrease in contents of major berry quality components of Cabernet Sauvignon and Shiraz with every one degree increase in temperature during fruit maturity

Quality components	Cabernet Sauvignon	Shiraz
Anthocyanin (mg /100 g peel wt)	41.93	300.36
Total Phenols (mg /100 g peel wt)	100.39	224.38
Total Flavanoids (mg /100 g peel wt)	13.00	138.37
Total Acidity (%)	0.002	0.02

Since the prevailing growing season temperatures are already high in the study areas as compared to other wine grape growing regions for these two varieties under study, the subsequent rise in temperatures would affect the quality of wine grapes. Once this season's analysis of quality components is complete the impact assessments scenario and region wise would be complete. Since the grape cultivation is amenable to manipulations in terms of regulating cropping season due to the practice of pruning in these growing areas it provides scope for adaptive strategies to be developed to harvest good quality grapes.

Objective: Quantified influence of extreme weather events on phenology of Mango

i) Monitoring of vegetative flushes and flowering of mango and variations in weather

The occurrences of extreme weather events are known to influence the phenology of perennial fruit crops. During recent past there have been reports on the variations in the occurrence of different phenological events in perennial fruit crops due to the prevailing temperature conditions. In mango the initiation of flowering depends on prevalence of low temperature and arid weather conditions during this crucial phenological stage, which ultimately determines the extent of production and months during which fruits are available in the market. Hence the monitoring of mango phenology in terms of occurrence of vegetative flushes and flowering was taken up this season. Under Bangalore conditions the normal vegetative flush was observed during July-August. Subsequently the flowering was expected during the months of December and January. However this year due to below average rainfall during the months of June, July, August and October except the month of September caused moisture stress. The total rainfall during these months was only 672.2 mm compared the average of 1969 to 2008 (841.46 mm) and also the average of 2000-08 (854.87 mm) (Table 31). Especially the moisture stress during the month of October caused flowering in trees where the mature shoots were available and vegetative flushing was also observed. Under high density orchard also the flowering was observed during the month of October and November. Majoring of the trees did not flower during this period.

Table 31. Average and total rainfall during 2009 in Bangalore compared to the long time average

Rainfall	1969-08	2000-08	2009
April	67.38	86.65	68.2
May	92.88	81.67	106.6
June	73.29	73.75	61.4
July	106.1	108.24	43.8
August	128.21	127.18	73.2
September	192.65	178.09	302.8
October	180.95	199.29	16.2
Total	841.46	854.87	672.2

In Bangalore conditions the normal flowering period is expected to be during the months of December and January. This year it did not happen due to the prevailing temperatures, which influence induction of flowering, were higher during the months of November and December. The minimum temperature plays a very crucial role in flowering of mango and the minimum temperatures were 18.13 and 16.74 ºC during the months of November and December, respectively as compared the long time averages (Table 32).

Table 32. Prevailing temperatures during the months of November to February 2009 in Bangalore compared to long time average

Months	1969-08		2000-08		2009-10	
	Max T	Min T	Max T	Min T	Max T	Min T
November	26.87	17.08	27.42	16.02	27.47	18.13
December	26.32	15.07	27.54	14.39	27.13	16.74
January	27.36	14.50	28.98	14.38	28.10	14.29
February	29.84	15.88	30.94	15.24	30.93	14.46

As the minimum temperatures dropped below 16ºC subsequently during the months of January and February the flowering occurred late in the months of February. Even flowering was profuse in the trees, which were in the advanced stage of bearing. Due to this in Bangalore region flowering was late and harvesting of fruits also is delayed due the weather variability.

CENTRAL SOIL AND WATER CONSERVATION RESEARCH AND TRAINING INSTITUTE

DEHRADUN

Objective: To calibrate and validate AVSWAT model for runoff, soil loss and other hydrological parameters for the selected watersheds of the country

Modeling Climate Change Impact

Choice of Watershed

The watershed chosen for the simulation of SWAT is the one ORP projects handled by CSWCRTI, Research Centre. In this project CSWCRTI has prepared a comprehensive plan with appropriate soil & water conservation treatment. The plan was executed by GSLDC, Forest and Agricultural department between 1985 and 1987. The watershed was monitored for runoff and sediment in successive years (1988 to 1996).

Description of watershed

Location

Navamota watershed is located in Khedbrahma taluka of Sabarkantha district in Gujarat state at 73.03^o East Longitude and 24.23^o N Latitude with MSL of 260 m. The total area of the watershed is 328.7 ha and is located 266 Km north of Vasad. The watershed drains into Sabarmati river which is nearly 1 Km downstream. The general climatic conditions of the study area are presented in Table 33.

Table 33. General Climatic information of the area

Parameters	Values of Navamota Watershed (Khedabrahma, Gujarat)
Longitude	73.03°
Latitude	24.23°
Altitude	260m
Annual rainfall	885 mm
Radiation index of Dryness	1.558
Budyko Evaporation	740 mm/year
Budyko Runoff	146 mm/year
Budyko Evaporation	83.50%
Budyko Runoff	16.50%
Aridity	Sub tropical and semi arid
Aridity Index	0.66
Moisture Index	-34 %.
Precipitation Deficit	456 mm/year
Climatic net primary production	Precipitation Limited

Rainfall

Rainfall in the area is irregular and erratic accompanied by gusty winds. Almost entire rainfall is received between the months of June to September. The average (1981-1996) annual rainfall of the area is 665 mm. Year to Year variations is quite pronounced. This wide variation (Standard deviation of about 312 mm) highlights the uncertainty of the rainfall in the area.

Temperature

The seasonal variation in temperature is quite wide. Average maximum and minimum temperature is 39.3°C (May) and 16.3°C (January), respectively.

SWAT Simulation

The Soil & Water Assessment Tool (SWAT) was used to simulate runoff and soil loss from Navamota watershed. The DEM has been derived from the ASTER 30 data (Fig.74) and was appropriately processed to scale down to a higher spatial resolution. The actual stream derived from high resolution Google earth data was digitized and subsequently burnt on the DEM to exactly focus on the intended outlet. The actual area of the watershed was calculated to be 328.77 ha.

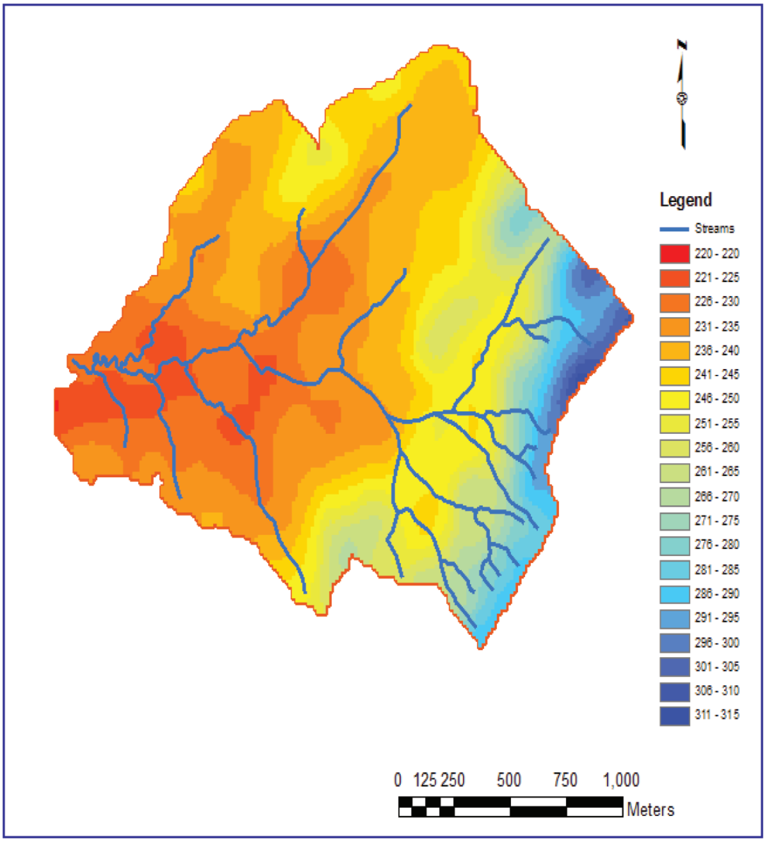


Fig.74. Generated high resolution DEM from ASTER 30 data with actual digitized streams from Google earth

Land use map

A land use map of Navamota (Gujarat, Khedabrahma) watershed has been prepared. The major crops database has been collected from published literatures and internet. Landsat ETM 7+ data merged with Google earth image has been used to classify the images based on comparable land-use patterns. The acreage of crops has been chosen based on relative membership of reflectance values to a particular crop's signature, time of the scene (Google Earth and landsat TM data) and available literature.

The major cropping pattern of the area is maize based intercropping system in rain fed area. As per the Landsat TM data analysis about 50.14 percent of the total area is under maize based cropping system. Other land use system encompasses forest land (13.82 percent) and degraded land / rock outcrops (36.03 percent). The details of the land uses are as shown in Table 34 & Fig.75.

Table 34. Landuse classes of Navamota watershed

Landuse	Area(ha)	% area
Maize based intercrop	164.83	50.14
Perrenial vegetation/ Forest	45.43	13.82
Degraded land	55.91	17.01
Rock outcrops	62.52	19.02

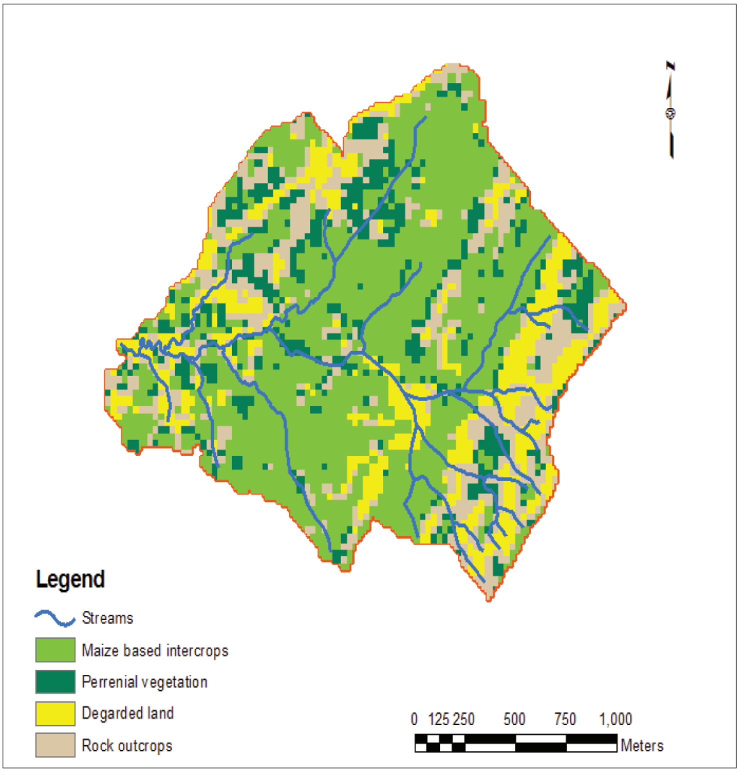


Fig. 75. Land use map of Navamota watershed

Soil database

The soil database used for the simulation is based on actual data of soil collected from Navamota watershed. Based on observations there were 7 distinct classes of soil with mostly gravelly in nature. Classifications were made based on depth of soil (varying from 7.5 cm to more than 90 cm with majority below 60 cm depth) and textural classification (Clay loam, Sandy loam). The detailed soil mapping is presented in Fig.76.

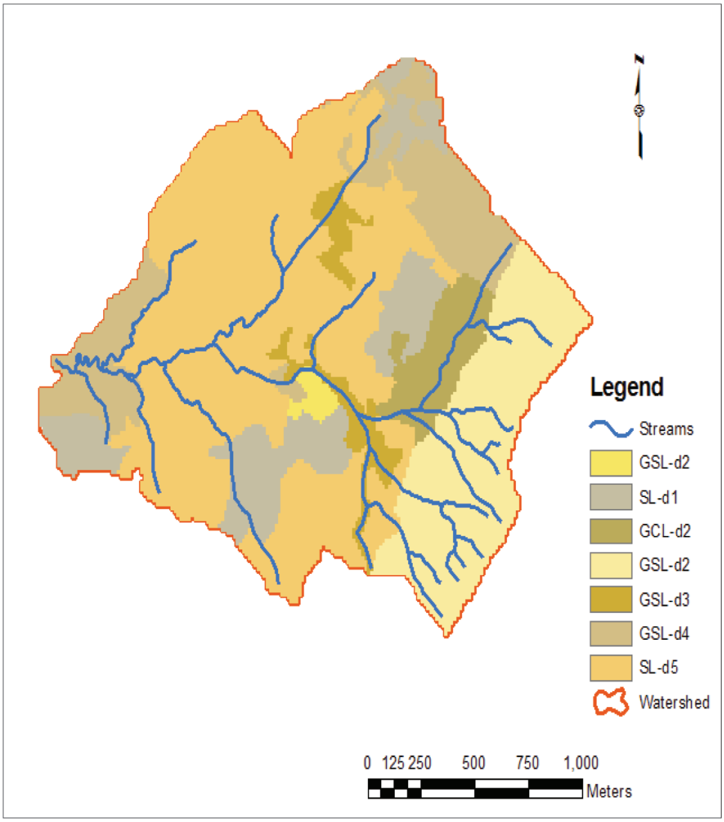


Fig.76. Soil map of Navamota watershed

Nomenclature:

GSL-d2 : Gravelly sandy loam with depth varying from 7.5 to 22.5 cm

SL-d1 : Sandy loam with depth less than 7.5 cm

GCL-d2 : Gravelly clay loam with depth varying from 7.5 to 22.5 cm

GSL-d2 : Gravelly sandy loam with depth varying from 7.5 to 22.5 cm (Higher gravel content)

GSL-d3 : Gravelly sandy loam with depth varying from 22.5 to 45 cm

GSL-d4 : Gravelly sandy loam with depth varying from 45 to 90 cm

SL-d5 : Sandy loam with depth more than 90 cm

Model Simulation

SWAT models were applied to the database of Navamota watershed (Khedabrahma, Gujarat) and the details of database are described below. The model was initially run for those years having observed runoff data (1992-1996) of which year 1994 to 1996 was used to calibrate the model and 1992-1993 was used to validate the model.

Database

Weather generator file

The weather generator file is the key for ascertaining missing variables in weather database used for SWAT simulation. The weather generator program (New_LocClim v1.1) was used to generate the swat weather generator parameters after appropriate downscaling.

Weather data

Weather data has been derived from PRECIS downscaled model prepared by IITM, Pune. There are gross difference between PRECIS base line data and actual weather data. With assumption that the difference between PRECIS baseline (1961-1990) and projected (2071-2100) is to be relied for climate change, thirty year monthly average of daily weather parameters of baseline data was subtracted from corresponding projected scenario data and the difference obtained were used for computing projected data from actual observed data. In case of rainfall, percentage difference between projected and baseline of monthly sum of 30 year average data were used as correction factor.

Crop database

The crop database used is as per the default database provided in SWAT model with some modifications based on available literatures. The management files in each HRUs or sub-basin is defined as per the average date of scheduling which encompasses the date of sowing, date of fertilization and harvest date as per the locality and heat units were exactly input as per the crop physiological needs.

Soil database

The soil database was taken partly from observation conducted during the watershed project planning phase by NBSSLUP, Regional Centre, Baroda in collaboration with CSWCRTI, Research Centre, Vasad (1984) and derived information using SSWATER software.

Observed runoff and sediment data

The watershed was monitored from 1987 to 1996. However the database for runoff was chosen for the period 1992-1996 due to its availability on a continuous basis. The monthly values were taken based on monthly summation of individual events. Some of the missing events were inter/extrapolated based on curve number procedure using the observed rainfall and runoff pair. The fitting procedure used was two parameter optimization models that find parameters S and initial abstraction parameters I_a simultaneously.

Model Setup and Sensitivity Analysis

Model setup was carried out with AVSWATX extension in Arcview 3.2 +Spatial analyst 2.0a. The grid files encompassing DEM, land use and soils were intersected in layers using most appropriate membership. The model was set with 13 sub-basins and 44 HRUs (Fig.77). The default SWAT database was used in cases where, data on watershed variables were obscure for initial setup. However, post initial swat run sensitive parameters identified using sensitivity analysis.

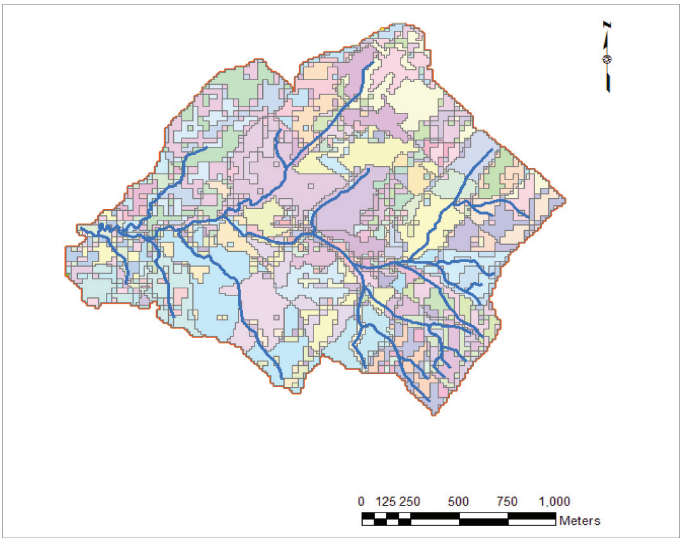


Fig.77. HRU discretization of the Navamota watershed

The sensitivity analysis with the observed runoff data (monthly denomination) revealed that the following parameters are important in a ranked configuration and their contribution to objective function and the simulated output. The choice of parameters to be calibrated was based on the relative importance in ranking towards both objective function and model output (Fig. 78).

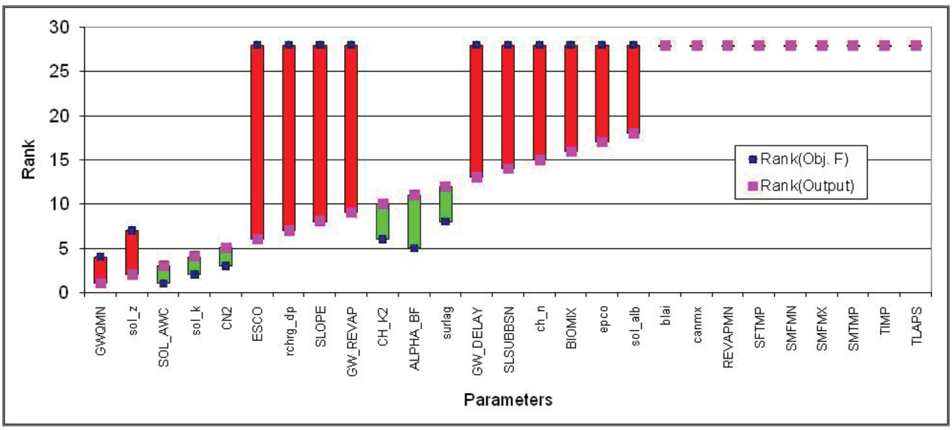


Fig.78. Relative importance of model parameters from sensitivity analysis on Objective function (SSE) and model output

The assorted model parameters rank (as per model output sensitivity) against the objective function rank reveals that, the parameters (a) GWQMN, (b) sol_z,(c) sol_k, (d) CN2, (e) CH_k2, (f) ALPHA_BF, (g) surlag, (h) SOL_AWC are important from the point of view of retaining their higher hierarchical ranks. Therefore the calibration was carried out with those 8 parameters.

Calibration and validation

To establish the model effectiveness to simulate hydrological responses to climatic variations the model was subjected to rigorous calibration with observed rainfall and runoff pairs on a monthly time scale. Data of runoff data from 1994 to 1996 was used to calibrate the model using the parameters as discussed earlier. The weighting of various parameters were done using simple replacement of parameters in some cases where as some parameters like CN2, sol_k, sol_z , SOL_AWC were changed with some fixed percentage (10 percent) in every successive calibration steps. The calibration result is shown in Fig.79. The model efficiency was calculated as 0.886 which is quite good representation of the model performance in simulating the observed runoff. The R-sq value represents the trend conformity of the model to their observed counterparts, which is seemingly well represented (0.9075). The slope component (0.8657) represents the model result consistently and underestimates the observed runoff by about 13 percent. Another reason for such discrepancy is that, base flow components (lateral flow as estimated using SWAT) is not included in the simulated runoff, where as in the case of watershed it is an existent phenomenon.

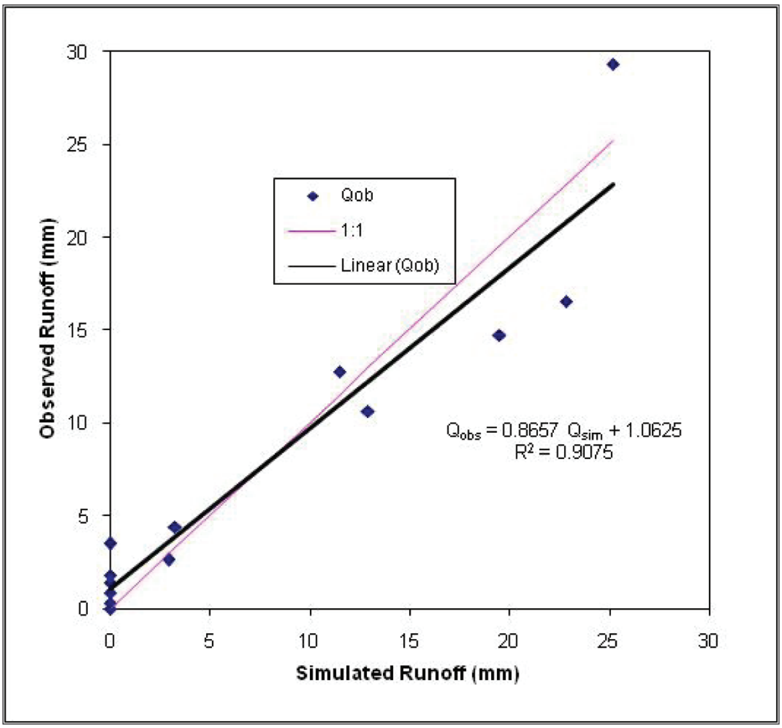


Fig. 79. Calibration of model output with their observed counterparts

Validation of the model was carried out using the observed data of 1992 and 1993 on surface runoff. The data of July 1993 was not included as the rainfall data of few events were not recorded for the month for some important events. The validation result is shown in Fig.80.

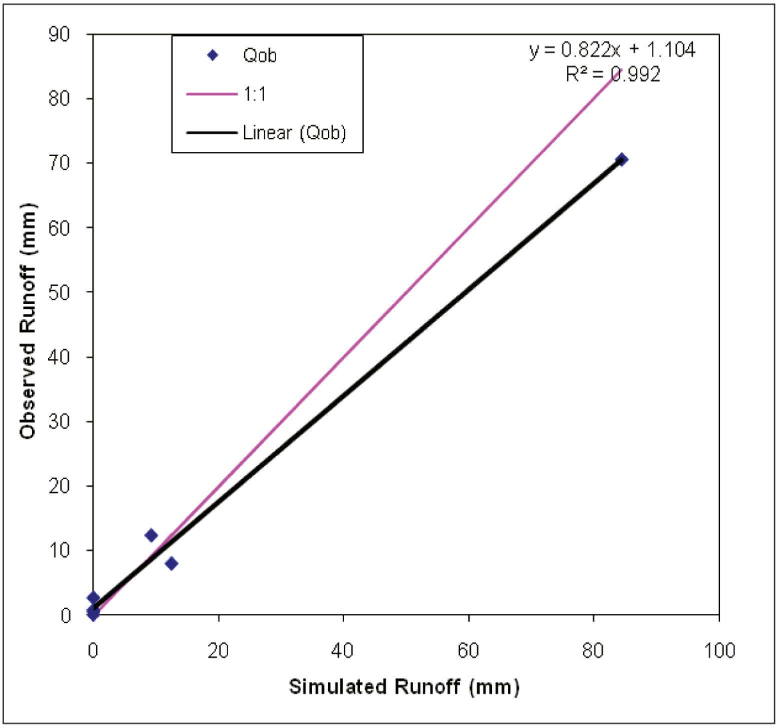


Fig. 80. Validation of model output with their observed counterparts

Though the observed data set for the said set is scanty, but the trend conformity is well represented (0.992) with the calculated model efficiency is 0.944. Similar to the calibration stage, the model validation also shows that the model underestimates the observed runoff by 17 percent.

Climatic projection simulation

Based on the availability of all weather parameters, the weather data from 1992 to 2002 is used as baseline scenario. The relative changes in weather parameters are derived from PRECIS data analysis discussed earlier in the document and was multiplied by a factor derived therein to represent the scenario in a 2071-2100 projected framework. The CO_2 factor was changed from 380 ppm in baseline scenario to 867 ppm in A2a Scenario. The model simulation result is as shown in Table 35.

Analysis of model output

The results/output provided from the baseline and projected scenario is presented in Table 35. Based on the above simulation result it can be inferred that, comparison to baseline data the projected scenario has registered the changes as follows with the same cropping pattern and management activities.

Table 35. Simulation Result (SWAT) from Navamota watershed

Simulation variables	Baseline (1992-2002)	Projected scenario (A2a)	% change in Projected with respect to baseline (%)
Precipitation (mm)	705.1	818.1	16.0
Surface runoff (mm)	45.27	67.7	49.5
Lateral soil discharge (mm)	4.74	5.69	20.0
Total aquifer recharge (mm)	350.49	418.84	19.5
Total water yield (mm)	311.49	398.06	27.8
Percolation out of soil (mm)	350.49	418.84	19.5
ET (mm)	305.8	327.1	7.0
PET (mm)	1382.1	1471.2	6.4
Transmission losses (mm)	0.12	0.14	16.7
Total sediment loading (t/ha)	1.136	2.267	99.6

Abiding by the PRECIS data, the present analysis of output revealed that, in the projected scenario, rainfall will increase by 16 percent, and PET and AET values will rise by 6.4 percent and 7.0 percent respectively over those in baseline years.

The higher sediment loss (99.6 percent) is evident due to enhanced percentage of runoff (49.5 percent) during the projected scenario than that of the baseline. In the projected scenario it is expected that total water yield will increase significantly by 27.8 percent of which groundwater contribution would be enhanced by 19.5 percent. This means better prospects for *Rabi* crops from supplemental irrigation point of view from the groundwater reserve. Better management of runoff would enhance better moisture regime post *Kharif* season and may add on to ground water reserve for use during *Rabi* season.

Salient findings:

- As per the usual notion of non-applicability of SWAT model to smaller watershed has been tested and the performance found to be satisfactory. However, the CN trends of individual HRUs found to be very less as compared to SCS handbook for the designated land uses. The reason may be a camouflaged effect of series of conservation structures which could have been treated separately to maintain the parity with the values as those in SCS handbook.
- The calibrated and validated SWAT model outputs found to be reasonably simulating the observed runoff values with model efficiency more than 0.88.
- Under the same cropping pattern and management activities, surface runoff and total sediment load, total aquifer recharge, Water yield, PET and ET are likely to increase by 49.5%, 99.6 %, 19.5%, 27.8%, 6.4% and 7.0 % respectively under projected condition with increase in rainfall by 16 %.
- The condition emphasizes even in a projected climatic contingency scenario, the water resources would not be hard hit, and however soil loss may be high which may be warranting various soil conservation activities in the upper part of the catchment. Since the watershed is already treated with series of water conservation structure it would be imperative to have more plantation activities up stream to arrest soil loss.

Objective: To quantify the suitability of various Watershed Management Measures for adaption to climate change (runoff and soil loss)

It is unanimously accepted that the climate change is reality and it is very likely that the rainfall, one of the important rather foremost input parameter in the production of agriculture and allied food products, will change with respect to spatial & temporal distribution, duration, intensity and total quantity during 21st centaury. The management of the rainfall for making it useful to agriculture is going to be very skilful involving the technological improvement and the cost. The cost of soil and water conservation (S&WC) measures is also going to be higher. It will be higher irrespective of increasing or decreasing rainfall. The major S&WC measures namely bunding, trenching, terracing, water harvesting, spillway construction, diversion drain etc are all going to be costly.

To start with the field bunding (every individual agriculture field is bounded by field bunding of appropriate cross section) is the most vulnerable S&WC measure. The objective of the field bunding is to impound the rainwater for marinating the soil moisture required for crop production, minimizing the risk of out flow of soil nutrients through runoff from the field and inducing underground water recharge. The principal behind any activity and particularly of that of the S&WC activity is that it should fulfill the desired objectives and the cost involved should be least. In case of the earth work involving activities, the volume of the earth work should be least and it can be achieved with the optimum height of the field bund. The height of the field fund normally equals the one day highest rainfall of 10 years frequency. Accordingly the height of the field in vast areas of the country is maintained at 25 cms. The side slope of about 1: 0.5 is normally recommended and maintained in the field bund. The cross section of the field bund in the medium and light soil differs in the top width. The width of the field bund in medium soil has been assumed as 10 cm and in the light soil as 15 cm.

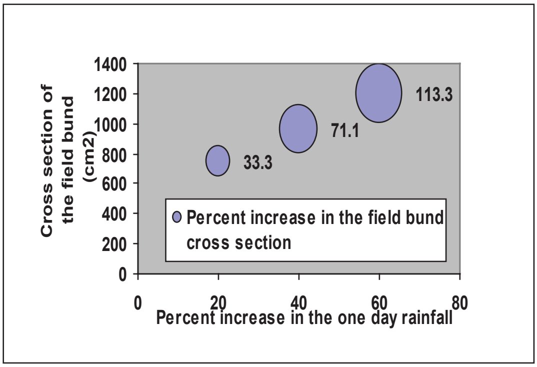
The cost of the field bund depends upon the length of the field bund per unit area and its cross section. The length varies as per the shape and size of the field; however the cross section does not vary. Thus the comparison of the cross section of the field bund will be appropriate to judge the cost of the field bund as the cross section multiplied by the length of the field bund will be the earthwork involved for that area. The height of the field bund will change as per the change in the one day maximum rainfall expected in the locality due to the change in the rainfall as a result of the climate change and thus the cross section of the field bund will change. The assessment of the change in the cost of the field bund has been made for an increase in the one day maximum rainfall by 20, 40 and 60 percent from the base period of 1961-1990.

Field bund in medium soil

The height of the field bund in medium soil works out to be 30, 35 and 40 cm with an expected increase in the one day maximum rainfall by 20, 40 and 60 percent respectively from the base period of 1961-1990.The cross section of the field bund with the height of the 30, 35 and 40 cm works out to be 750,962.5 and 1200 cm2. The percent increase in the cross section is 33.3, 71.1 and 113.3 percent from the cross section of the base period of 1961-1990 (Table 36; Fig.81 (a) and (b).

Table 36. Field bund cross section and the climate change

Parameters	Probable increase in the rainfall (%) over the rainfall of 1961-1991				Remarks
	1961-1990	20	40	60	
Height of the field bund (cm)	25	30	35	40	
1. Cross section (cm2)	562.5	750	962.5	1200	Medium soil
% increase in the cross section	-	33.3	71.1	113.3	-
2. Cross section (cm2)	687.5	900	1137.5	1400	Light soil
% increase in the cross section	-	30.9	65.5	103.6	-



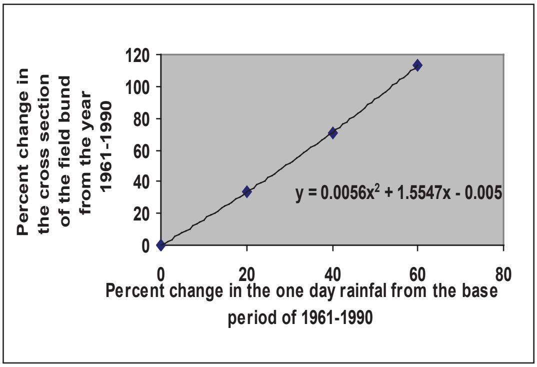
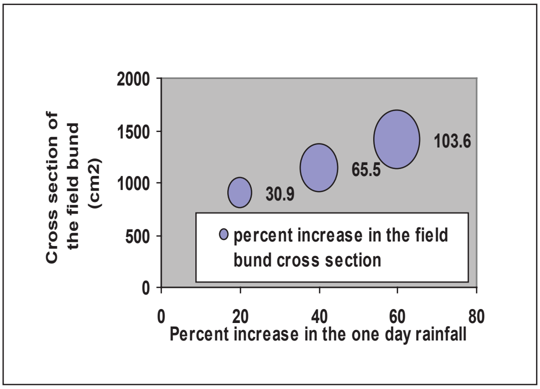


Fig.81. (a) Cross section of the field bund and the rainfall increase in medium soil

(b) Empirical relationship between Cross section of the field bund and the rainfall increase in medium soil

Field bund in light soil

The height of the field bund in light soil will be same as that in the medium soil i.e. 30, 35 and 40 cm with an expected increase in the one day maximum rainfall by 20, 40 and 60 percent respectively from the base period of 1961-1990.The only change in the top width is considered. The side slope has also been considered same as in the case of medium soil because the increased side slope will increase the base and the area lost will be unacceptable by the farmers. Further the filed bund with this base will remain stable and only some seepage of water may take place to the adjoining field. The cross section of the field bund with the height of the 30, 35 and 40 cm works out to be 900, 1137.5 and 1400 cm2. The percent increase in the cross section is 30.9, 65.5 and 103.6 percent from the cross section of the base period of 1961-1990 (Table 36; Fig.82 (a) and (b).



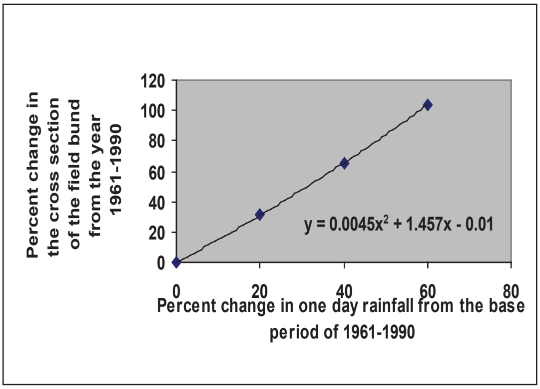


Fig.82. (a) Cross section of the field bund and the rainfall increase in light soil

(b) Empirical relationship between Cross section of the field bund and the rainfall increase in light soil

Empirical relationship

The following polynomial second order equation have been developed relating the percent increase in one day rainfall with percent increase in the cross section of the field bund.

for medium soil

Y=0.0056 X2 + 1.4457 X -0.005

for light soil

Y=0.0045 X2 +1.457 X -0.01, Where,

Y=percent increase in the cross section of the field bund, and

X= Percent change in the one day maximum rainfall

ICAR RESEARCH COMPLEX FOR EASTERN REGION

PATNA

Objective: To calibrate and validate Infocrop model for key food crops in different agro climatic regions of Bihar

The historical meteorological data was analyzed to identify the long-term changes in temperature and rainfall. The available weather data was divided into two time slots baseline (1961-90) and post 1990 (1991-2005). An attempt was made to study the influence of monsoon season rainfall variability on rice production in Bihar. Weather data was further analyzed to find the extreme weather events that are days having more than 45^{0}C maximum temperature, less than 1^{0}C minimum temperature and rainfall more than 180 mm. Field experiments to identify the effects of different dates of sowing on three different varieties (varying in maturity duration) of rice was carried out at ICAR-RCER experimental farm.

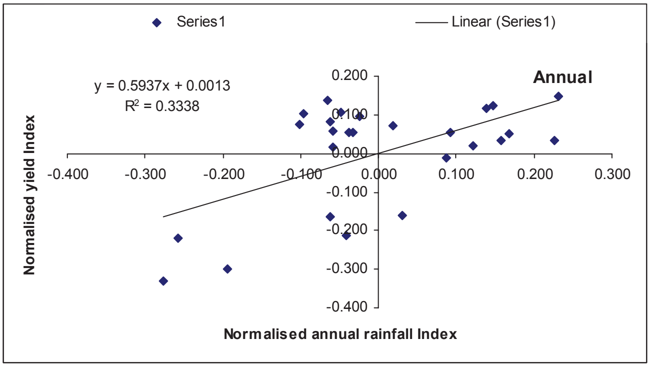


Fig.83. Relationship between Normalized Annual Rainfall Index (NARI) and Normalized Yield Index (NYI)

Baseline and post 90s showed an increasing trend in annual rainfall for all stations except Madhepura, where there is decreasing trend for the baseline. Annual maximum temperature showed decreasing trend while annual minimum temperature showed increasing trend for all stations, post 1990. However, for baseline, a mixed trend was observed for maximum as well as minimum temperature. Productivity of rice showed a decreasing trend from the year 2000 to 2005. Rainfall during kharif season as well as annual rainfall also showed a decrease during the same time period. Multiple regressions of normalized yield and rainfall indices indicated that *kharif* season and annual rainfall accounted for 29% and 33% variability in rice productivity (Fig.83). The number of days having maximum temperature of more than 45^{0}C in a year on an average, days having minimum temperature less than 1^{0}C and days with excess rainfall were estimated, results showed that the number of days with temperature more than or equal to 40^{0}C has decreased although days with temperature above 30^{0}C either increased or remained constant after 2000. On an average days with minimum temperature less than or equal to 10^{0}C has decreased after 2000 for all stations showing progressive increase in minimum temperature. Results of Patna station is shown in Fig.84. The HADCM3 generated mean rainfall (mm/ day) and temperature (^{0}C) 2020, 2050, and 2080 were extracted from nearest grid points covering the study area. The INFOCROP model was calibrated and validated for wheat, rice and maize crops.

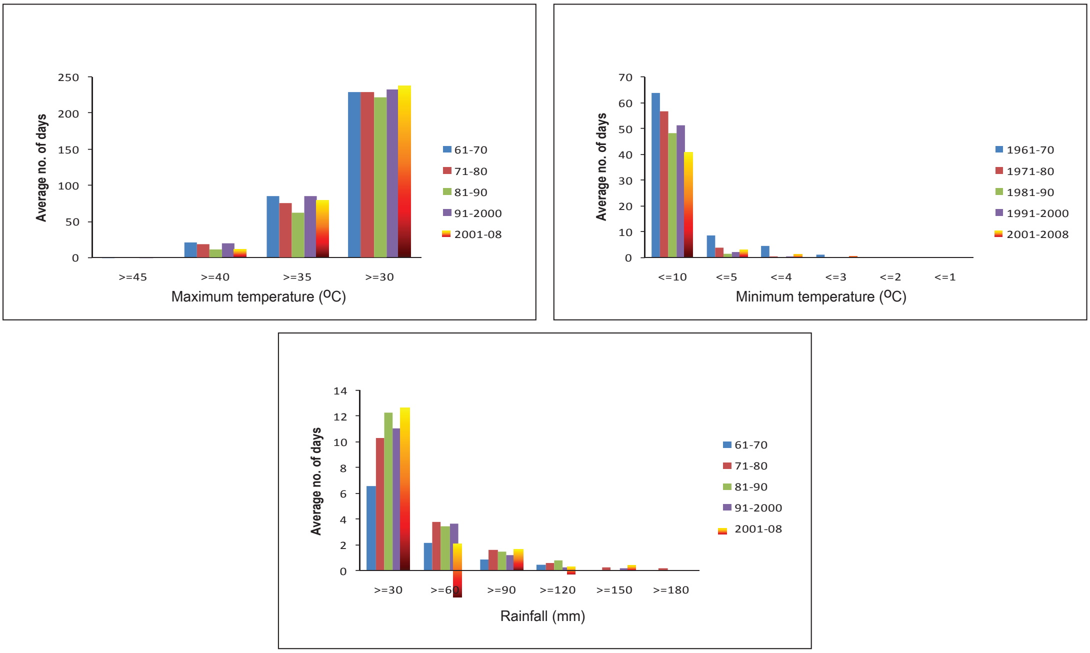


Fig.84. Frequency of extreme temperature and rainfall events at Patna

Objective: To simulate the impact of different scenarios of climate change on crop production in Bihar

For assessing the impact of climate change on crop production, HadCM3 predicted changes in rainfall and temperature under A2 and B2 emission scenarios and PRECIS RCM data for A2 scenario were taken. HadCM3 generated mean rainfall for the period 2020, 2050, and 2080 were extracted from the grid points covering the study area. The mean rainfall and temperature data for stations, under consideration were extracted for crop modeling. Percentage change in mean monthly rainfall and average changes in minimum and maximum temperature were estimated for the period 2020, 2050, and 2080.

Station wise pooled data as presented in figure 3 showed that yield of all varieties of rice decreased from baseline under B2 scenario. Maximum decline in yield was observed for long duration variety (Radha) followed by medium (Sita) and short duration variety (Saket-4). Yield of timely sown wheat decreased by 7% and late sown by 23% for 2080s. For *kharif* maize decrease in yield was observed by 3, 7 and 12% for 2020, 2050 and 2080. Rabi maize was showing an increasing trend in yield. Similar trend in yield was observed for rice, wheat and maize crops for other stations also. Simulation studies conducted with for Pusa for PRECIS RCM A2 data during 2080 predicted less decrease in medium and long duration varieties of rice from baseline as compared to the simulation studies done with GCM data, for the rest of the crops the simulation studies suggest that the decrease in yield was more as compared to GCM based simulation.

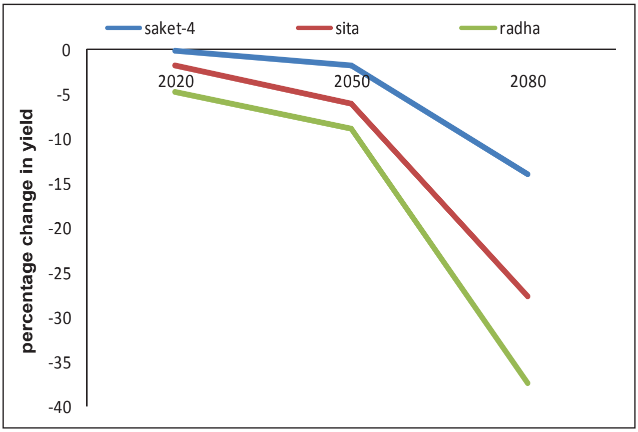


Fig.85. Percentage changes in yield of rice (variety wise) pooled for all the stations

Objective: To quantify the suitability of various agronomic and land and water management measures for adaptation to climate change

Rice

Simulation studies carried out for Pusa showed that by decreasing the seed rate from 40 kg to 30 kg/ha increased the yield marginally for short duration variety only. Age of seedling at the time of transplanting was varied by 5 and 10 days. Transplanting the seedlings earlier than normal transplanting increased the yield in all the three varieties for 2020, 2050 and 2080 as presented in Fig. 86. In short duration unirrigated variety of rice transplanting five days earlier as compared to normal practice (21 days) was more beneficial than 10 days earlier transplanting. Advanced sowing of rice by 14 days, increased the production of rice for all agro-ecological zones of Bihar.

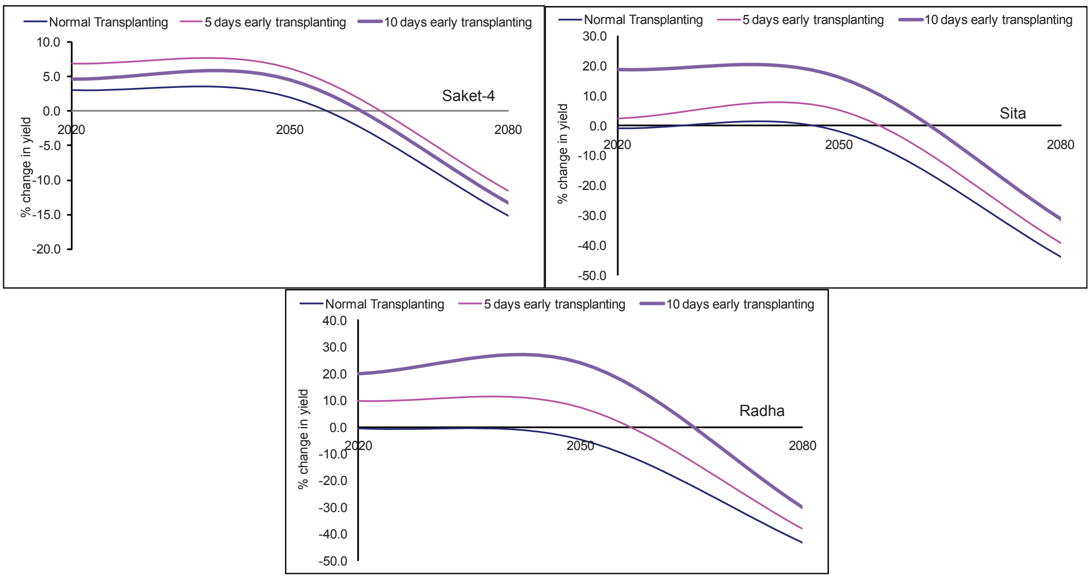


Fig. 86. Effect of early transplanting of rice compared to normal transplanting at Pusa

Wheat

In wheat, 7 days advanced sowing as compared to 14 days advancement with 180 kg was beneficial for all stations however Sabour was benefited more as compared to other stations. At Pusa 7 days advance sowing with 120 kg nitrogen increased the yield marginally for 2020, but when coupled with higher doses of nitrogen *viz.,* 150 kg and 180 kg the yield increased, but increase was more in 2020's as compared to 2050 and 2080. At Madhepura and Patna, advanced sowing with increased nitrogen showed almost no or marginal increase in yield.

Maize

Advancing the sowing of maize grown in *kharif* season by 7 days increased the yield for all stations, except for Sabour, where the yield increase was noted only for 2080 time period. Other adaptation strategies are being worked out for other stations.

ITKs were collected from different districts of Bihar and report was sent to P.I.NPCC during the month of December 2009. The districts covered under the survey were Bhojpur, Nalanda, Banka, Bhagalpur, East Champaran, Patna, Jahanabad, Buxar, Vaishali, Samastipur, Muzzafarpur, Nawada, Darbhanga.

Objective: To develop integrated modeling framework for coupling hydrologic model with crop water demand, water allocation and socio-economic models

Bhavani basin which is lying upstream of the Bhavanisagar Reservoir was selected for assessing the climate change impact on hydrology and water resources availability in the basin. For assessing the impact of climate change on streamflow, HadCM3 predicted changes in rainfall and temperature under A2a and B2a emissions scenarios were considered. HadCM3 generated mean rainfall for the period 1980, 2020, 2050, and 2080 were extracted from the grid points covering the Bhavani basin and interpolated using Inverse Distance method. The mean rainfall for 16 rain gauge stations, which were considered for hydrological modeling, was extracted and percentage change in mean monthly rainfall were estimated. Similarly, temperature data were extracted from the grid points covering the basin and basin wide average changes in minimum and maximum temperature were estimated for the period 1980, 2020, 2050, and 2080. For hydrological modeling, IHACRES (Identification of Unit Hydrograph and Component Flows from Rainfall, Evaporation and Streamflow data) model was calibrated and validated using the observed streamflow data of Nellithurai gauging station.

There is decrease in rainfall in most of the months in the basin under A2a as well as B2a scenarios. Maximum decrease of 45.20 and 51.90% was observed in the month of February 2020 under A2a and B2a scenario, respectively. During the month of July and August there is increase (though less than 10%) in rainfall under both A2a and B2a emission scenario.

During calibration period, the Coefficient of Determination and Nash-Sutcliffe Coefficient was found as 0.80 and 0.78, respectively for Nellithurai gauging station. The model was found to perform satisfactorily during validation phase too with Coeff. of Determination and Nash-Sutcliffe Coefficient of 0.79 and 0.76, respectively. Simulation results using HadCM3 predicted changes in rainfall and temperature under A2a and B2a emission scenarios indicated increase in annual streamflow during 2020 under both the emission scenarios (Fig.87), where as there is decrease in annual streamflow during 2050 under both the emission scenarios. There is decrease in streamflow during monsoon season under B2a emission scenario in all the three periods (2020, 2050 and 2080) whereas there is increase in streamflow during pre-monsoon season. Similar results were obtained in case of A2a emission scenario, except during 2050 monsoon seasons and 2020 pre-monsoon.

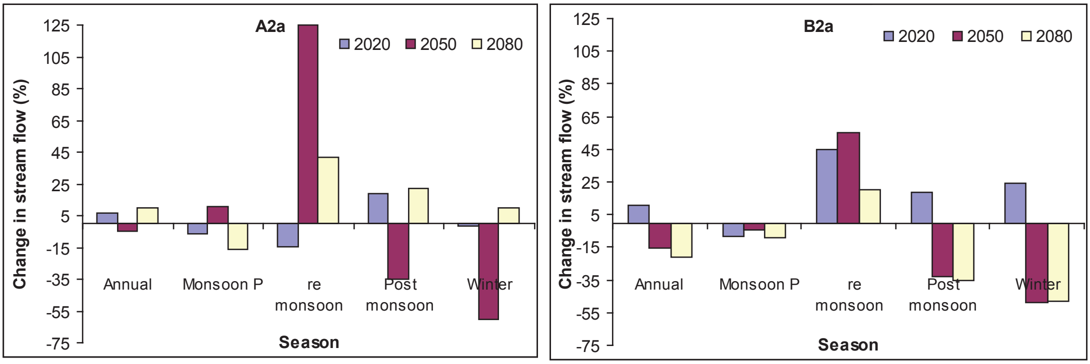


Fig. 87. Changes in seasonal and annual streamflow

NATIONAL DAIRY RESEARCH INSTITUTE
KARNAL

1.0 Thermal stress and mitigation in cattle and buffaloes

Apparently twelve healthy female each of Sahiwal cattle, Karan Fries cattle and Murrah buffaloes comprising six growing (8-12 months) and six adult (18-24 months) of each breed were selected from the herd of National Dairy Research Institute (NDRI), Karnal.

The experimental animals were maintained as per the standard practices followed at the institute. The animals were fed as per the availability of fodders during experiment and water was available *ad libitum* round the clock.

Each group of Sahiwal, KF and Murrah buffaloes were exposed in climatic chamber and natural environmental conditions. The experimental conditions were as follows:

a. Exposure at 20^{o}C and 40-45% RH - for 4 hours.
b. Exposure at 30^{o}C and 40-45% RH - for 4 hours.
c. Exposure to 40^{o}C and 40-45% RH - for 4 hours.
d. Natural Exposure to open environment in winter.
e. Natural Exposure to open environment in summer.

Measurement of oxygen consumption, heat production, physiological responses, heat loss from skin and respiratory system and environmental variables were recorded before exposure, after 2 hr and 4 hr of exposure.

The surface area of animals was measured from surface integrator that consisted of two equal sized wheels mounted with a revolution counter on a body. One of the wheels of the hand held integrator while on movement left an impression of chalk marker on the skin surface of animal. The area was calculated from the distance travelled over the skin and distance between two wheels.

The skin surface temperature at different sites of the experimental animals, viz, forehead, ears, shoulder region (proximal scapula) and flank regions were recorded with non-contact infrared thermometer (Raytek, Model Raynger ST2L, M/s. Surrey Scientific, Surrey, U.K.) by keeping it 8-10 inches away from the desired skin site.

The O_2 consumption of animals was measured on a modified Benedict Roth Collins Spirometer (Instruments and Chemicals, Ambala) with a 30 cm diameter bell and a mask made up of mild iron sheet and rubber was used. The rate of decline of O_2 of bell was recorded on a Kymograph moving at a speed of 5 cm/ min. The oxygen consumption in litres per minute was calculated from the slope of curves. The volumes thus obtained were corrected to standard temperature pressure. Heat production was calculated from oxygen consumption and 1 litre of oxygen was assumed to be equal to 20.46KJ.

Since the major route of heat exchange between animals and its environment is radiation, convection, conduction and evaporation from skin and pulmonary system.Heat exchanged by Radiation, conduction and convection between animal body and surrounding environment were calculated by using Stefan-Boltzmann law of radiation, heat transfer. The emissivity of buffalo skin surface = 0.96 and emissivity of cattle skin surface=0.98 Connective heat exchange between animal body and surrounding environment (J/sec) was calculated using heat transfer coefficient of air and taking into wind velocity and surface area of animal. Conductive heat exchange between animal body and surrounding environment (J/sec) calculated using thermal conductivity of air 0.026.

Evaporative heat loss through Skin and pulmonary system were measured. Ventilated capsule method was used for measuring heat loss through skin. The heat loss through respiratory tract was measured using a mask made of thin aluminium fitted to the mouth of the animal with rubber tube. The temperature and humidity of ingoing and outgoing air was measured using the digital hygrometer. Heat and/or moisture increment was calculated using psychrometric chart and on the basis of mass of air exchanged losses from skin or respiratory surface were calculated.

Results

Metabolic heat production

The pre-exposure heat production in Murrah buffaloes varied from 1571.2 ±143.2 to 2527.6 ± 129.6 KJ/hour. The increase in metabolic heat production in growing and adult animals was in the same pattern as oxygen consumption. The percent increase in metabolic heat production at 40°C was 46% and 23%, at 20°C 10 and 9% in growing and adult buffaloes, respectively.

Heat exchange

The major route of heat exchange between animals and its environment is radiation, convection, conduction and evaporation from skin and pulmonary system. The buffaloes lost the heat from the body surface to the environment at 20°C and winter season through radiation, convection and conduction in both growing and adult animals. The magnitude of loss of heat was higher from body to environment through radiation, which varied from 912.2±35.86KJ/h to 1186.6±153.89 KJ/h followed by convection 306.7±13.4 to 370.4±36.2 KJ/h and conduction 2.2±0.1 to 2.5±0.8 KJ/h in growing buffaloes during winter. Similar trend in proportion in heat loss through conduction, convention and radiation in adult animals were observed.

The heat exchange through radiation, convection, conduction and evaporative heat loss (sweating and panting) depends on the surface area per unit body weight, magnitude of the temperature gradient between animal and air.

At 40°C the animal body received heat from the surrounding through radiation, convection and conduction in both growing and adult buffaloes after 2 hours of exposure. As the exposure temperature of buffalo increased to 40°C the conductive and convective heat gain decreased. This may be due to animals increase their body temperature to activate the process of sweating and panting.

The pre-exposure heat gain was 890.9±32.1, 242.9±9.3 and 3.7±0.6 KJ/h in growing buffalo and 1368.3±52.3, 323.3±8.4 and 4.2±0.4 KJ/h at 40°C in adult buffaloes through radiation, convection conduction, respectively. When the growing and adult animals were exposed to 40°C for 4 hours continuously radiative, convective and conductive heat gain decreased to 1286.4±47.1 KJ/h through radiation, 290.9±5.7 KJ/h through convection and 3.6±0.7 KJ/h through conduction.

The Heat loss through skin and pulmonary system before exposure at 30°C temperatures was 964.6±56.6 and 328.7±24.8 KJ/hr increased to 1686.9±152.4 and to 388.2±20.4 KJ/h after 4 hrs of exposure in growing buffaloes calves respectively. Initially higher value of heat loss through sweating and panting was registered in adult buffaloes. The higher heat loss through sweating and panting in adult buffaloes compared to growing animals is related to higher surface areas in adult buffaloes compared to growing animals and the total heat storage per animal is also higher in adult animals.

The absolute value increased to 2445.8±176.3 and 2560.6±152.4 KJ/h through sweating and 450.8±34.8 and 525.9±20.4KJ/h through panting after 2 and 4 hours of exposure in adult buffaloes at 30°C in climatic chambers. The heat loss through skin and pulmonary system of adult buffaloes increased with the increase in temperature (40°C).

At temperature 20^0C both KF and Sahiwal cattle dissipated heat to surrounding environment through sensible heat loss i.e. radiation, convection and conduction. The mean heat loss by radiation, convection and conduction to environment in growing KF was 872.7±128.1, 254.4±12.5 and 1.9±0.4 KJ/hr and in adult KF was 1386.6±165.46, 494.5±29.4 and 2.7±0.3 KJ/hr, respectively. The heat loss increased to 912.6±46.12, 278.2±16.2, 1.6±0.7 KJ/hr in growing KF and 1574.8±2.13, 544.7±38.2 and 1.7±0.5 KJ/hr in adult KF after 4 hours of exposure respectively at exposure-I. The mean heat loss by radiation, convection and conduction after 4 hours exposure of growing Sahiwal at 20°C was 902.5±76.1, 258.7±23.2 and 1.6±0.2 KJ/hr over the pre exposure mean value of 862.6±78.1, 284.7±12.2 and 2.5±0.8 KJ/h, respectively.

The heat loss to environment after 4 hours of exposure of adult Sahiwal at 20°C was 1394.8±132.1, 474.8±28.5 and 2.4±0.5 KJ/hr by radiation, conduction and convection over the pre exposure value of 1206.4±105.4, 414.1±34.4 and 3.2±0.7 KJ/hr, respectively.

At 30°C after 4 hours of exposure young Sahiwal gained heat at a rate of 148.4±42.4, 18.5±3.5 and 1.0±0.8 KJ/hr and adult Sahiwal cattle at a rate of 320.7±47.6, 38.2±5.2 and 1.3±0.5 KJ/hr by radiation, convection and conduction respectively. Large sized adult animals exchanged more heat with surrounding by radiation, convection and conduction due to surface area per unit body weight, thermal gradient between animal and air.

The heat loss to environment from growing Sahiwal increased from 862.2±34.6 to 1116.5±164.6 KJ/hr by radiation, 288.2±12.3 to 360.7±23.6 KJ/hr by convection, 1.9±0.2 to 2.2±0.5 KJ/hr by conduction in winter season. Similarly heat loss to environment in adult Sahiwal increased from 1242.7±175.9 to 1458.6±185.6 KJ/hr by radiation, 396.8±26.4 to 420.7±23.2 KJ/hr by convection, 3.1±0.7 to 1.9±0.6 KJ/hr by conduction after 4 hours of exposure in winter season. In the winter season skin temperature is higher than environmental temperature therefore animal lost heat to environment by radiation, convection and conduction.

When both growing and adult group of Sahiwal were exposed to natural environmental conditions in summer season, these animals gained heat by radiation, convection and conduction and lost the heat through evaporation from skin and by respiratory passage. In Growing Sahiwal heat gain by radiation, convection and conduction varied at the rate of 752.3± 52.7 to 712.5 ± 45.8 KJ/hr, 214.8 ± 14.3 to 188.3 ± 18.4 KJ/hr, 2.8 ± 0.5 to 2.6 ± 0.4 KJ/hr after 4 hrs of exposure to natural environment in summer.

Adult Sahiwal exposed to natural environmental conditions, heat gain varied from 1190.6 ± 102.6 to 1158.6 ± 154.8 KJ/hr by radiation, 292.4 ± 11.8 to 256.7 ± 14.8 KJ/hr by convection and 3.6± 0.6 to 2.9± 0.2 KJ/hr by conduction after 4 hrs of exposure.

Heat loss through Skin and Pulmonary system

The heat loss through skin evaporation varied from 1254.5 ± 76.54 to 1986.7 ± 42.4 KJ/hr and loss from pulmonary system varied 384.6 ± 14.7 to 448.4 ± 24.3KJ/hr in growing Sahiwal. The respective heat loss were 1688.3 ± 74.5 to 3046.4 ± 52.46 KJ/hr from skin and 522.8 ± 26.8 to 575.0 ± 30.4 KJ/hr from pulmonary system in adult Sahiwal.

The heat loss in growing Sahiwal exposed to III climatic chamber condition varied from 2826.2 ± 45.3 to 3845.2 ± 104.6 KJ/hr through skin and 612.6±33.7 to 722.5±12.5 through pulmonary evaporation after 4hrs of exposure. In adult Sahiwal heat loss through skin varied from 3848.5 ± 142.1 to 464.2.2 ± 132.5 KJ/hr and from pulmonary system 711.2±23.8 to 812.5±42.2.

During summer, heat loss from skin of growing Sahiwal varied from 2712.7±28.6 to 3286.6±86.54 KJ/hr after 4 hrs of exposure and evaporation through pulmonary system 367.7±22.6 to 529.7±38.7 KJ/hr by and in adult Sahiwal heat loss varied from 3682.2±94.67 to 3956.7± 42.3 KJ/hr by evaporation through skin and 650.6±26.6 to 782.6± 16.5 KJ/hr by evaporation through pulmonary system.

The study concluded that during summer and hot-humid period animals are unable to maintain their body temperature and heat abatement devices like fan, mist cooling are unable to dissipate body heat and body temperature of buffaloes and cows producing milk are 1.5- 2 C higher than their normal temperature, therefore more efficient cooling devices should be used to reduce thermal load of lactating animals.

Methane emission: Effect of diets and feed stuffs

In order to assess methane emission in different breeds of cattle and effect of feeds on methane emission in different breeds expired air were monitored at pre and post feeding periodic intervals using open/ closed circuit system.

Animals maintained at the Institute under normal conditions of feeding and management were monitored for methane emission in expired air during the year. Methane was measured by closed/ open circuit system at different intervals. Open circuit system has been extensively used in animal calorimetric measurements and been practiced for monitoring changes in oxygen, carbon di oxide and methane. The system is in use at NDRI, Karnal to refine the values of methane conversion rates, methane emission from cattle and buffaloes. The open circuit system consists of a multistage centrifugal pump driven by an induction motor. In the open circuit system the flow rate of air is chosen so that the concentration of methane remains less than 0.2% in the air either distal to animal or in expired air. The flow rate of air is monitored either on rotameter or using a velometer. A sample of expired air/exhausted air was dried out and passed for monitoring of gases (Analytical Development Corporation, England). The change in gas concentration in the airflow was measured during the day or any specific period in relation to time of feeding. The methane emission was calculated as the product of the flow rate, the time and the average methane concentration. To check precision of methane emission periodically, the air was also drawn through a facemask worn by animal while standing or through closed chamber. In routine practice the expired gas of animals is also collected in Douglas bag, volume measurements are made prior to monitor of oxygen, Carbon dioxide and methane. The periodic checks on accuracy of the system are also performed on the basis of recovery of methane gas after release of known quantity of methane in the chamber.

Results

The results on methane emission at different intervals have been presented in Table 37. The Sahiwal and Tharparkar cattle were observed to emit low methane at pre and post feeding intervals than crossbred cattle.

Methane emissions of buffaloes maintained on different diets were measured and it was observed that addition of greens to wheat straw diet reduced methane emission. Animals maintained on Jowar and concentrate mixture produced / emitted more methane. The study concluded that addition of green mustard or mustard cake in the diet of buffaloes help in reducing methane emission (Table 38).

Table 37. Methane emission at different intervals by different cattle breeds

Cattle Breed	8.00-10.00 (l/h/animal)	10.00-2.00 (l/h/animal)	12.00-2.00 (l/h/animal)	2.00-4.00 (l/h/animal)	4.00-6.00 (l/h/animal)	24hrs (lit/d/animal)
Sahiwal	0.88±0.16	2.63±0.25	5.03±0.16	5.81±0.21	6.98±0.31	96.65±7.16
Tharparkar	1.37±0.23	3.56±0.17	4.97±0.38	5.97±0.18	8.06±0.16	124.97±17.47
Karan Fries	1.89±0.63	4.78±0.48	6.15±0.52	7.86±0.19	9.11±0.32	133.23±9.30
Karan Swiss	1.01±0.17	4.79±0.65	9.26±0.5	8.62±0.44	9.24± 0.45	141.99±11.21

Table 38. Methane emission on different feeds in growing Buffaloes

Feed	Methane (l/d/animal)
Berseem + Green mustard @ 10 Kg each	74.88 ±10.23
Bhusa+ green forage+ mustard cake@250g	82.54 ± 4.89
Complete feed Block + straw, Jowar 2kg	88.18 ±17.19
Bhusa+ Green Maize @10 kg	91.12 ± 6.95
Maize or green grass @ 5 kg/day and two times in a day	120.71 ± 22.50
Jowar + Concentrate mixture	221.01 ± 24.52

To measure influence of milk production level on methane emission from dairy animals Interrelationship between methane and milk production in buffaloes

Interrelationship of methane emission with milk yield of buffaloes was assessed. Buffaloes producing milk 1500 - 2800 lit / annum were monitored for methane emission and milk yield. Milk composition was determined periodically for fat, SNF and corrected for FCM.

The methane emissions of Murrah lactating buffaloes were estimated and the interrelationship of methane with milk production was worked out. The results revealed that the milk yield limitedly influence methane emission in Murrah buffaloes. For an increase of the milk yield from 3,500 to 5,000 kg FCM/buffalo /year a reduction of methane emission of nearly 1- 2 g kg-1 FCM-1 was observed. The methane emissions were 15.0 to 20 g CH4/kg FCM from enteric fermentation in buffaloes. In the present study no significant effect of buffalo milk production with enteric methane emission could be established, however methane emission per liter of produced milk decreased with increase in milk.

Methane mitigation through herbal feeds

An attempt was made to standardize dose response of different feed additives to mitigate methane emission in vitro. In order to assess effect of herbal preparations on methane emission and its mitigation in vitro experiments were performed using fenugreek, mustard and garlic. All the three ingredients were microwave heat treated and grinded. The concentrations used were 10, 20 and 40 mg%.

The results indicated that Fenugreek and mustard affect methane production in vitro at different concentrations and methane produced per unit of feed decreased with increase of fenugreek and mustard content in diet. The levels of Feed additives were able to decrease methane levels in relation to doses used. The energy loss in methane declined due to addition of Fenugreek and mustard without influencing quantity of total gas. The garlic formulation at different concentrations used was found to have no influence on methane production in vitro (Table 39).

Table 39. Effect of fenugreek, mustard and garlic on methane production (In vitro)

		% Methane	Total gas (ml)/g substrate	Methane (g)/100g substrate
Control		$26.91^{a} \pm 1.71$	$285.83^{a} \pm 8.21$ 5	$.49^{a} \pm 0.35$
F1	20	$19.74^{b} \pm 0.71$	$291.67^{a} \pm 10.14$	$4.11^{b} \pm 0.24$
	40	$17.86^{b} \pm 0.32$	$335.83^{bc} \pm 14.24$	$4.29^{b} \pm 0.25$
	80	$16.39^{b} \pm 0.56$	$286.67^{a} \pm 17.1$ 3	$.35^{b} \pm 0.25$
M2	20	$17.23^{b} \pm 0.31$	$290.0^{ac} \pm 7.50$ 3	$.57^{b} \pm 0.12$
	40	$16.47^{b} \pm 0.35$	$320.0^{c} \pm 5.80$	$3.39^{b} \pm 0.37$
	80	$16.64^{b} \pm 0.16$	$358.0^{b} \pm 3.0$	$4.26^{b} \pm 0.05$
G3	20	$25.66^{a} \pm 0.39$	$301.67^{ac} \pm 5.07$	$5.53^{a} \pm 0.14$
	40	$26.56^{a} \pm 2.16$	$306.67^{ac} \pm 11.67$	$6.62^{a} \pm 0.45$
	80	$26.59^{a} \pm 0.77$	$342.50^{b} \pm 5.00$	$6.51^{a} \pm 0.27$

Values with similar superscripts do not differ significantly in a column

Identification of methane mitigation technologies for livestock and estimate the enteric methane mitigation potential on a regional scale

The work is in progress and different ITK's are being identified.

Adaptation of livestock: Role of HSP's

The adaptive response of buffaloes was studied by comparative HSP 72 quantification.

Methodology

The growing, heifer and lactating Murrah buffaloes were exposed in climatic chamber at 38± 1°C with 50± 2%RH and 42 ± 1° C with 40 ± 2 %RH and HSP 72 quantification was done as follows.

The comparative quantification of HSP72 gene was performed using MxPro(Mx3005 stratagene) Software with programme: comparative quantitation (calibrator).The reaction mixture for HSP72 gene was prepared separately in two replicates both for the target gene and the house keeping gene. Each reaction mixture contained the 2.0 µl cDNA. The reaction was performed in the final concentration of 10 µl. The PCR conditions used as was - initial

denaturation of 2 min at 50ºC; followed by 45 PCR cycles (denaturation- 95ºC for 10 min; annealing temperature 95 ºC for 30 sec; extension- 60 ºC for 1 min). The amplification results were interpreted by considering '0' hour as calibrator (climatic chamber), 0th day (summer and winter season) and GAPDH as endogenous control (Normalizer). After each reaction dissociation curve (melting curve) was run to check the specificity of the PCR product.

Fluorescence was acquired in each cycle in order to determine the threshold cycle or the cycle during the log-linear phase of the reaction at which fluorescence rose above background for each sample. During analysis, the MxPro software automatically adjusted the levels of the gene of interest in both unknown and calibrator wells to compensate for differences in the levels of the normalizer. The normalized value for each unknown sample and calibrator were derived by using delta CT method. The normalized target values were divided by the calibrator normalized target values to generate the relative expression quantity. Fold change values (x) are calculated using the following formula: x=2 -ΔΔ Ct. The data thus generated was directly imported in micro excel work sheet.

Results

The HSP72 mRNA expression increased significantly ($P<0.05$) after 1 and 2 hour of exposures in growing heifers during both the exposures whereas, in lactating buffaloes a declining trend was observed after one hour of exposure. The magnitude of increase in the expression of HSP72 mRNA was significantly ($P<0.05$) higher during exposure II (42±1ºCand 40±2%RH) compared to exposure I (38±1ºCand 50±2%RH) in all groups of buffaloes.

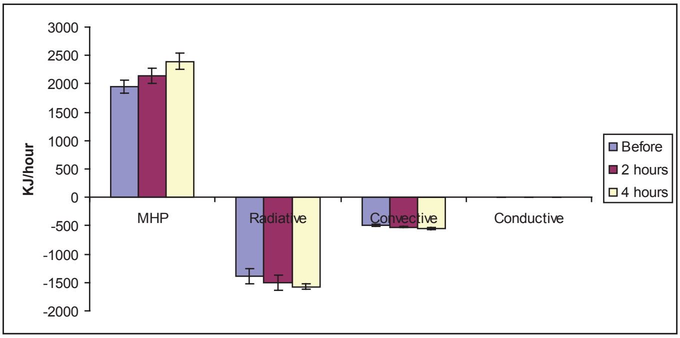


Fig.88. Heat production and exchange in adult Murrah buffaloes at 20 °C temperature

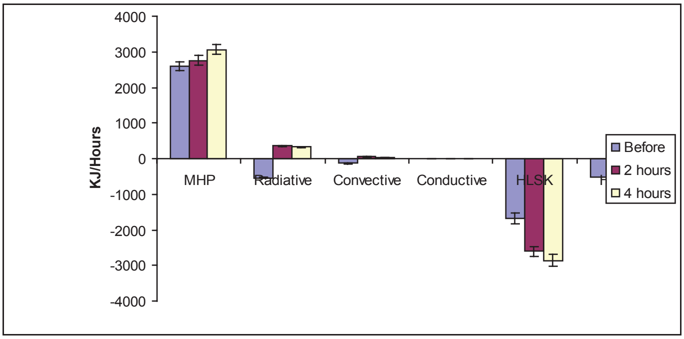


Fig. 89. Heat production and exchange in adult Murrah buffaloes at 30 °C temperature

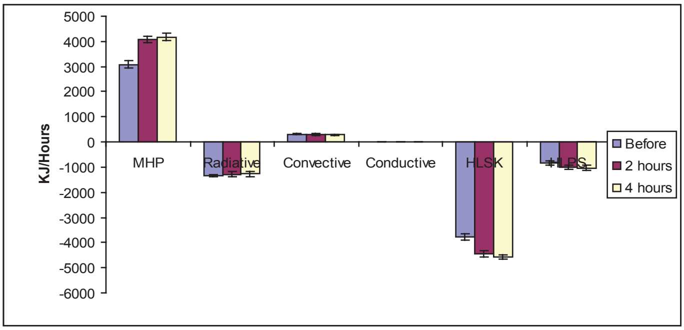


Fig.90. Heat production and exchange in adult Murrah buffaloes at 40°C temperature

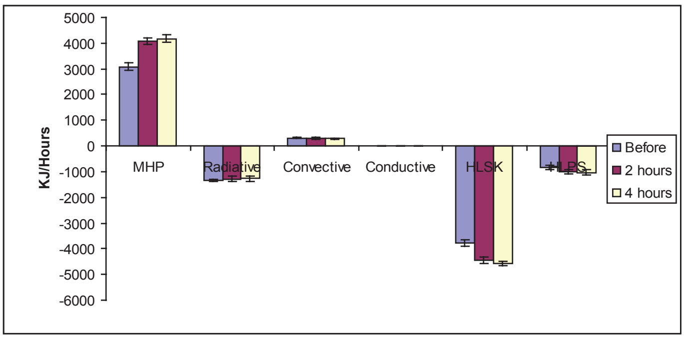


Fig. 91. Heat production and exchange in adult Murrah buffaloes during summer

CENTRAL MARINE FISHERIES RESEARCH INSTITUTE
COCHIN

Objective: To conduct basic, applied and strategic research for quantifying the region – specific vulnerability of Indian marine fisheries to increasing climatic variability and climate change

Seasonal and interannual changes in oceanographic features and their impact on small pelagic catches off Kerala

The catch of small pelagics, especially that of the oil sardine *Sardinella longiceps* has increased from 1,554 tonnes in 1994 to 2,50,469 tonnes in 2007 in the upwelling zone off Kerala (southwest coast of India). Time series data of different climatic and oceanographic parameters gathered from different sources showed that, during 1967-2007, the annual sea surface temperature increased by 0.15°C per decade (Fig. 92a); scalar and zonal wind speeds also increased during these four decades (Fig. 92b). The SST is increasing; the surface winds are strengthening and the coastal upwelling index during southwest monsoon increased by nearly 50% from 1997 to 2007 (Fig. 92c). This substantial increase in CUI elevated the chlorophyll *a* concentration during monsoon (Fig. 92d). The high concentration and increasing trend of Chl *a* during the monsoon resulted increase in of over 200% in annual average Chl *a* concentration. The increasing CUI and Chl *a* during monsoon sustained an increasing catch of oil sardine during post-monsoon season (Fig. 93). This trend indicates that the current warming is beneficial to herbivorous small pelagics. The pathway of increase in oil sardine catches is given in Fig. 94.

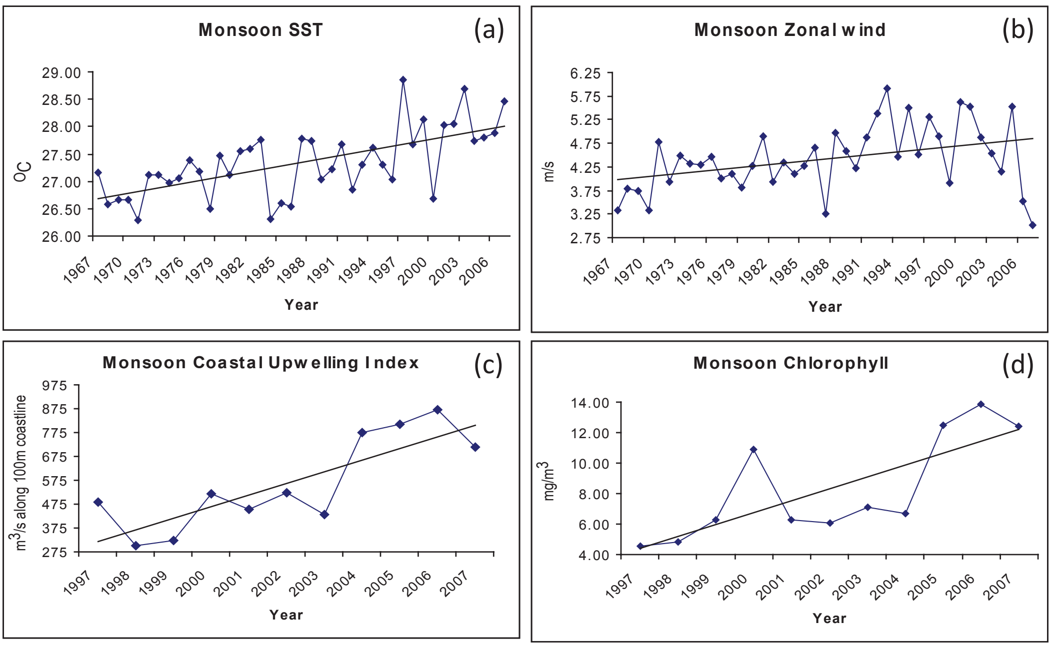


Fig. 92 (a-d). Changes in oceanographic parameters off Kerala

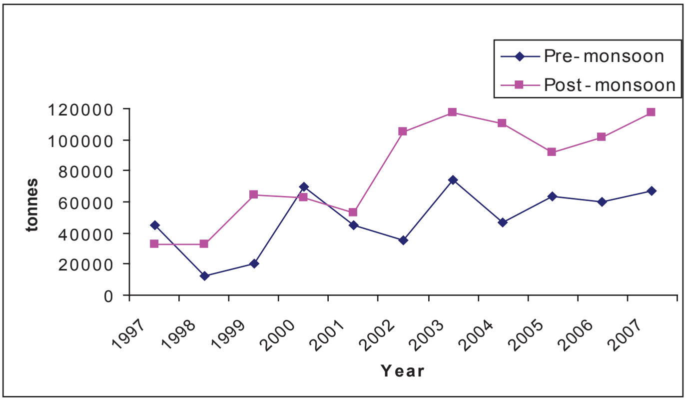


Fig. 93. Increase in the catches of oil sardine off Kerala

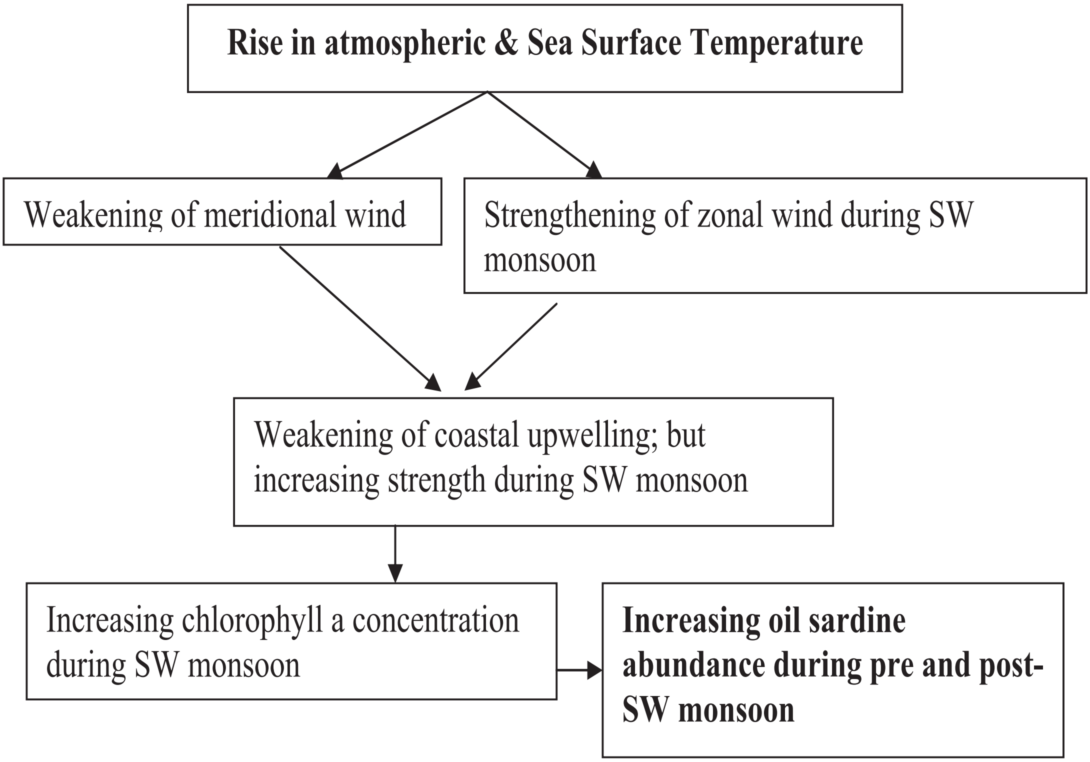


Fig. 94. A schematic diagram on the pathway for increased oil sardine abundance along Kerala coast during 2000-2009

Objective: To develop adaptation strategies for minimizing negative impacts

Vulnerability of coastal fishing villages of Maharashtra to sea level rise

About 75 coastal fishing villages of Maharashtra are located within 100 m from the high tide line. This information has been collected from surveys undertaken by the field staff of CMFRI. To find out the vulnerability of these fishing villages to sea level rise, validation of available primary data from vulnerable fishing villages along Maharashtra coast was completed by ground truth by using GPS. For ground validation, data were collected from GCPs (Ground Control Points) at different elevations from all 5 coastal districts of Maharashtra, and images were generated for all five coastal districts of Maharashtra state.

To find out the area likely to be inundated by 1 m sea level rise, Google Earth Professional software, and other basic softwares for large image processing, like OCR and WinZip, was used for enhanced image and data processing. After geo-referencing these villages, three different SLR (Sea Level Rise) scenarios were created to determine critical area adjacent to the coast, likely to be submerged. Base mark (0 m), points at 0.3 m, 0.6 m and 1.0 m were obtained through software to calculate the perimeter and area for three SLR scenarios. All elevations are generated from mean sea level by the software. The results were validated by ground-truth during field observations.

The GIS profile of coastal fishing villages that are likely to be affected due to rise in sea level by 0.3 m is given in Fig. 95.

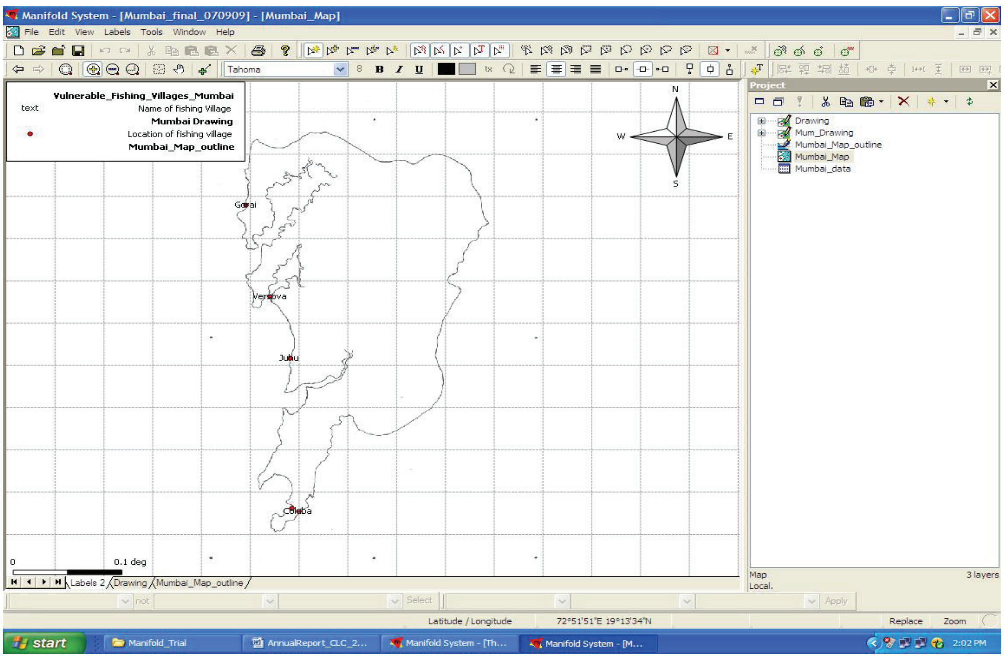


Fig. 95. The GIS profile of coastal fishing villages in Mumbai District likely to be affected due to rise in sea level by 0.3 m

Among the 75 coastal villages that are located within 100 m five coastal districts (Thane, Mumbai, Raigad, Ratnagiri and Sindhudurg) of Maharashtra, it was found that 35 villages in Raigad and Ratnagiri districts would be affected due to rise in sea level by 0.3 m (Table 40).

Table 40. Area (km^2) of coastal fishing villages in Maharashtra likely to be submerged due to sea level rise by 0.3 to 1.0 m

District	No. of villages	0.3 m	0.6 m	1 m
Thane	8	0.95	1.04	1.45
Mumbai	5	0.12	0.19	0.28
Raigad	19	0.29	0.38	2.03
Ratnagiri	16	0.005	0.05	0.332
Sindhudurg	27	0	0	0.905
Total	75	1.365	1.66	4.997

Survey on Indigenous Technical Knowledge of fishermen on climate change

Interview with 591 fishermen from the states of Maharashtra, Kerala and Chennai, has provided information on weather-related ITK of coastal fishermen and how best the ITK could be intergrated for advancement of scientific research to evolve options to adapt to climate change. The following conclusions could be drawn from the interviews:

1. Marine fishermen have heard about climate change, but are confused with annual climatic variabilities and climate change.
2. The perceptions on climate change and adaptation options differ between fishermen of different states.
3. They believe that reduction in fish catch in recent years is essentially due to juvenile exploitation, habitat destruction and overfishing (Fig. 96).
4. Fishermen attach maximum importance to wind direction and speed as the drivers of fish abundance and availability, followed by rainfall and temperature (Fig. 97). They believe that direction and speed of wind and temperature have changed over the last 20 years, which will have adverse impact on fisheries.
5. Sea erosion in Kerala and Tamilnadu, cyclones in Maharashtra and Tamilnadu and sea status off Maharashtra are perceived as major safety concerns.
6. In the event of cyclones and sea erosion, fishermen of Tamilnadu prefer temporary exit from their villages; their counterparts in Kerala prefer temporary exit as well as permanent rehabilitations to interior dwellings.
7. A large majority of fishermen listen to and follow daily weather bulletins in the media. They are prepared to take weather related insurance if the premium is within their capacity.
8. Fishermen believe that fish catches will decline in future. However, they do not want to leave the profession, but want their children employed in government jobs.

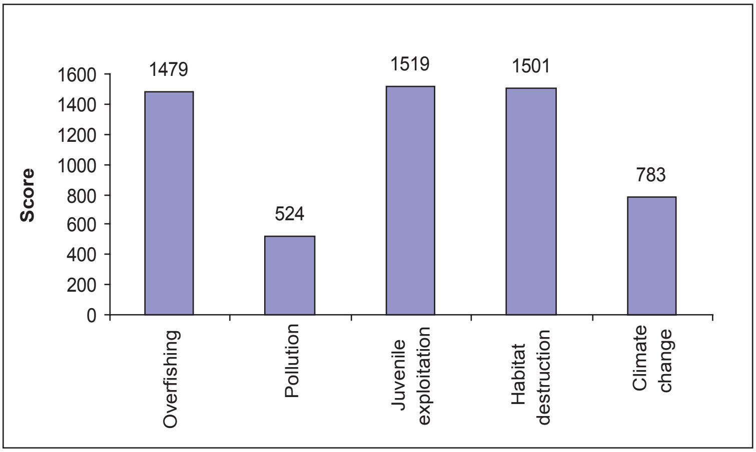


Fig. 96. Issues in marine fisheries (the values are pooled scores for three states based on fishermen response)

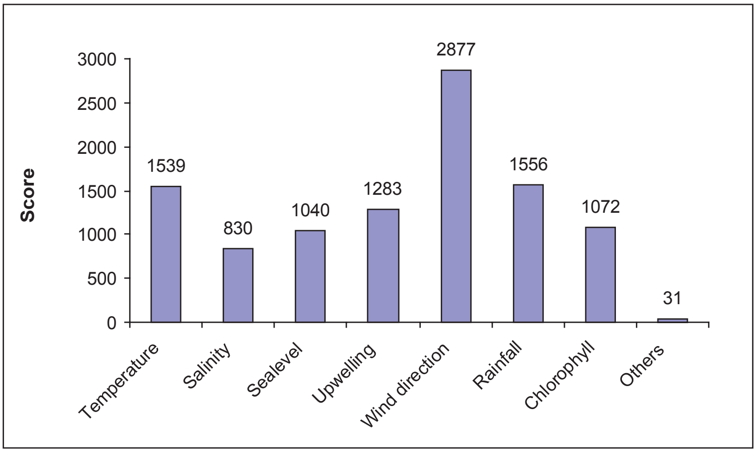


Fig. 97. Importance of climatic and oceanographic parameters to fisheries (The values are pooled scores for three states based on fishermen response)

The above conclusions enable suggesting the following recommendations for evolving adaptation options:

1. To enhance awareness on climate change, regular meetings between scientists and fishermen, participation of fishermen in oceanographic research cruises, and participation of scientists in community forum are necessary.
2. As perceptions about climate change and adaptation options differ between fishermen of different states, the scope of the interviews may be extended to other maritime states.
3. As the situation is different between states, the status of climate change and fisheries has to be assessed separately for each maritime state for evolving adaptation options.

4. Fishing and climate change are strongly interrelated pressures on fish production and must be addressed jointly. Reducing fishing mortality in the majority of fisheries, which are currently fully exploited or overexploited, is the principal means of reducing the impacts of climate change. For sustaining fish catches, implementation of conventional fisheries management plans such as Code of Conduct for Responsible Fisheries and Ecosystem-based Fisheries Management is necessary.

5. As wind (and thereby current and watermass movement) is an important driver of fish distribution and abundance, the climate-marine fisheries models may take into consideration the changes in speed and direction of meridional, zonal and scalar winds and currents to predict catches and evolve scenarios.

6. GIS maps need to be developed to identify coastal villages vulnerable to sea level rise and erosion.

7. Government preparedness is necessary by devising rehabilitation plans, installing suitable coastal protection structures and increasing beach areas. Governments should consider strengthening Weather Watch Groups and decision support systems on a regional basis.

8. Schemes may be devised to promote weather-linked insurance to the fishermen. Governments may also provide subsidies on insurance premium.

9. Allocating research funds to analyze the impacts and establishing institutional mechanisms to enable the sector are important.

CENTRAL INLAND FISHERIES RESEARCH INSTITUTE
BARRACKPORE

Objective: Impact of drought on fish seed hatcheries and nurseries in West Bengal

The survey covered fish seed producing hatcheries in 5 Districts in South West Bengal. A total of 50 hatcheries were surveyed randomly, using the State Fisheries Department participant list as the source for survey contacts. A total of 34 hatcheries responded to the survey for a 23% return rate. We received several responses that did not fit our objectives with respect to size and fish species cultured etc. Therefore, only 25 responses were analyzed for this report. These 25 responses represent 54% of the West Bengal State fish seed industry with respect to size and species cultured. The responses represent all major fish seed production areas in the state.

In a total of 25 numbers of fish seed hatcheries 23 (92%) were affected by the weather conditions in the state. A total of 20% of the seed producing hatcheries were affected due to high temperature and 12% were affected by water scarcity. Jointly high temperature and water scarcity affected 68 % of the total number of hatcheries surveyed.

Increasing trend of temperature

In North 24 Parganas mean maximum air temperature increased by 1.87 ºC between January to April and 1.47 ºC in May to September, 2009. The mean minimum air temperature increased by 0.35 ºC and 0.60 ºC in January to April and May to September respectively during 2006-09 (Fig. 98).

In Bankura district mean maximum air temperature increased by 0.46 ºC between January to April and 0.55 ºC in May to September. The mean minimum air temperature increased by 2.88 ºC and 2.56 ºC in January to April and May to September respectively during 2006-09 (Fig. 99).

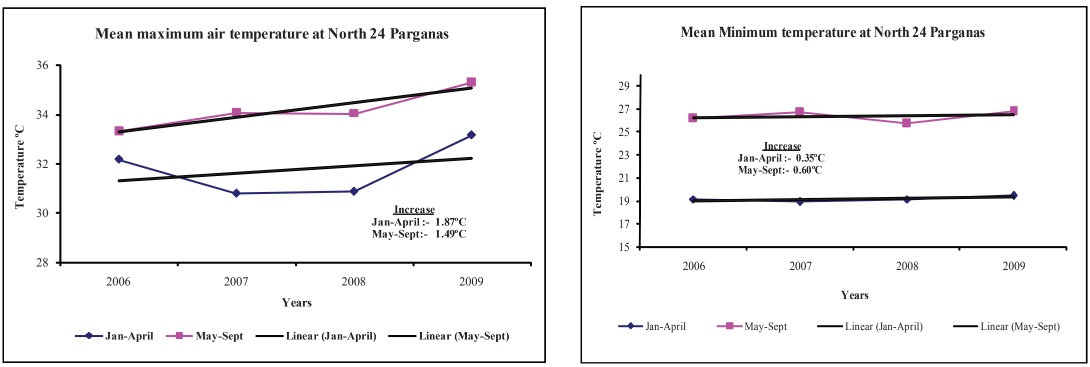


Fig. 98. Trend of temperature rise in North 24 Paraganas, West Bengal

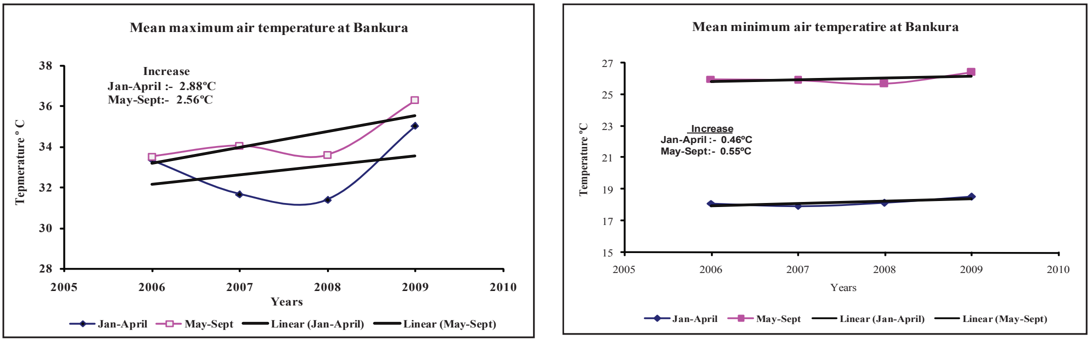


Fig 99. Temperature rise in Bankura, West Bengal

Deficient Rainfall

Deficient rainfall was recorded in 12 districts of West Bengal during 2009. During monsoon period June to September rainfall a deficit of 15% rainfall during March-May was recorded. Fish breeding practices in districts of West Bengal starts just after first week of February with the first spawn becoming available by mid March. Thus rainfall from March to September is important during the breeding season of fishes. During 2009 rainfall in March- 20.6mm (-25%), April- 2.0 mm (-96%), May- 229.2 mm (+146%), (cyclone "AILA" occurred in May), June-69.6 (-71%), July- 278.7 (-11%), August-329.6 (+6%) & September- 293.9 (+9%) respectively occured (Fig. 100). In the district of North 24 Parganas rainfall was deficient by 29%, Bankura by 27%, Burdwan by 23% and Hooghly by 34% in the fish breeding months of March to September.

Fish seed production in West Bengal is highly concentrated around Naihati in North 24 Parganas & Ramsagar in Bankura district of West Bengal, which has developed a large fish seed market and facilitates the marketing and distribution of seed within and outside West Bengal. Therefore, these two districts were taken as model, to analyses the overall climate change effect on fish seed hatcheries in West Bengal.

It has been observed that, about 12% of fish seed hatcheries were affected by deficit rainfall, 20% high temperature and 68% by low rainfall and high temperature in districts of Bankura and North 24 Parganas.

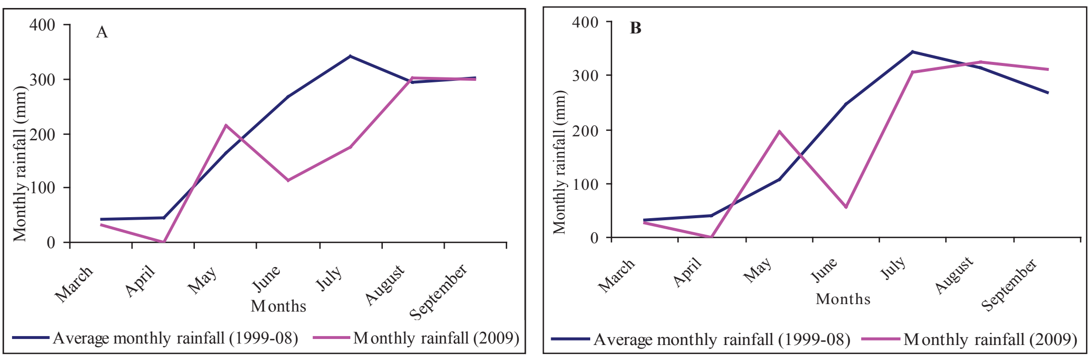


Fig.100. Averages rainfall distribution scenarios during 1999-08 and 2009 in (A) North 24 Paragans (B) Bankura in West Bengal

Economic loss

An economic loss analysis for these two districts for assessing the economic loss to fish seed production due to water scarcity in monsoon season (Fig.101) in the state was done, based on our previous and present study in 2006 & 2009, respectively. In relation to above scenarios, about 61% & 73% loss in income occurred during 2009 as compared to 2006 in Naihati and Ramsagar respectively.

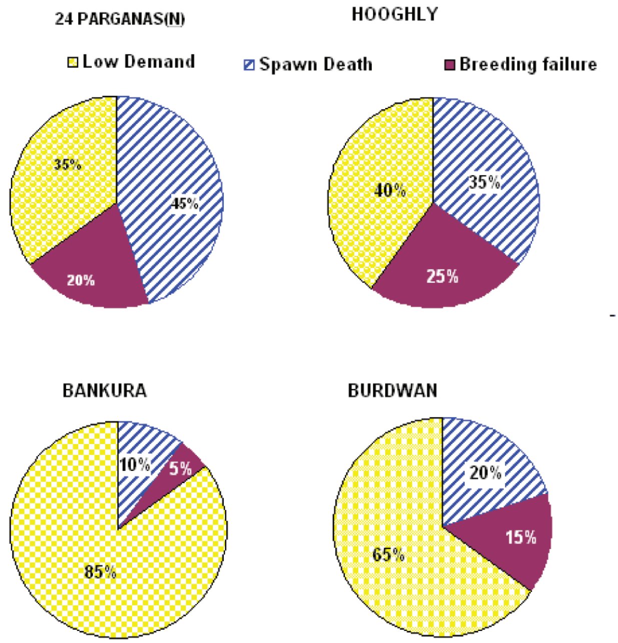


Fig.101. Percentage attributes impact due to drought condition in four districts

Three attributes viz. spawn death, breeding failure and low demand for fish seed were taken into consideration for assessment of impact of scanty rainfall and high temperature in four districts of West Bengal. Among the attributes spawn death was maximum (45%) at district 24 Parganas while breeding failure was maximum (25%) at district Hooghly (Fig.101). In district Bankura the maximum loss due to low demand of fish seed which was 85% among the other three attributes.

Fish Species Diversification for adaptation

It has been observed, that above 80 % of the hatcheries because of the prevailing drought condition diverted from rearing Indian Major Carps to other species like Pangasius (*Pangasius sutchi)*, *Puntius javanicus* and Magur (African catfish), which favorable adopt to water stress and high temperature condition. Where as this rate were 60% in 2006. (According to the previous survey, 2006).

1. The mean minimum air temperature of North 24 Parganas increased by 0.35ºC and 0.60ºC in January to April and May to September respectively and in Bankura district mean minimum air temperature increased by 2.88ºC and 2.56ºC in January to April and May to September respectively during 2006-09.

2. In the district of North 24 Parganas rainfall was deficient by 29%, Bankura by 27%, Burdwan by 23% and Hooghly by 34% in the breeding months of March to September.

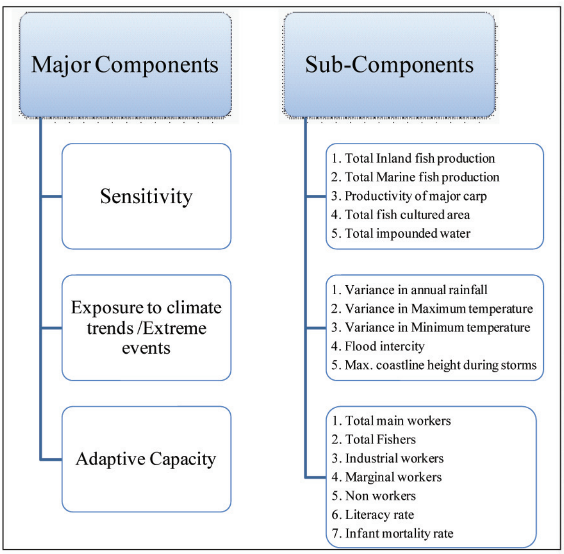
3. The total number of 23 out of 25 i.e. 92% of the fish seed hatcheries were affected by the weather conditions in the state. Low demand of fish seed as well as low survival rate due to drought in hatcheries and nurseries.

4. In relation to above scenarios, about 61% & 73% loss in income occurred during 2009 as compared to 2006 in districts of North 24 Parganas & Bankura, respectively.

Objective: Assessment of Vulnerability of Inland fisheries to Climate Change in West Bengal

To construct the Vulnerability Index for fisheries sector, following components were determined from five major areas: Demographic Profile, Fisheries profile, Occupational, Geographic and Climate Variability and rearranged them in IPCC frame work of vulnerability definition. Each is comprised of several indicators or sub-components (Table 41). These were developed based on Secondary data available on the published literature on each major component.

We developed a method for calculating the VI that incorporates the IPCC vulnerability definition. Table 41 shows the rearrangement of the sub-components from five major areas in three major components as defined in VI–IPCC framework. Exposure of the study of climate variability is measured by the average standard deviation of the maximum and minimum annual temperatures and annual precipitation over a 10-year period. Adaptive capacity is quantified by the demographic profile of a district (e.g., infant mortality rate, density of population etc), the types of workers employed (e.g., predominately fisheries, agriculture or also collect natural resources to sell in the market) and last, sensitivity is measured by assessing the current state of a district's fisheries resources and fresh water availability and production status.



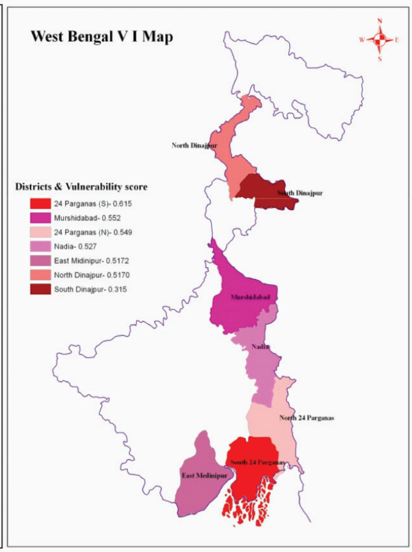


Table 41. Components in IPCC frame work

Calculation of Vulnerability Index

The IPCC provides a useful working method for assessing vulnerability (V) by describing it as a function of exposure (E) of climate change, sensitivity (S) to climate change, and adaptive capacity (AC).

The Vulnerability Index may be defined as: V =f (E, S, AC).

The vulnerability scores for each major components is the linear weighted (weights taken, because each of the sub-components is measured on a different scale) sum of standardise scores of sub components. These standardisations were calculated by employing the following formulae.

$Y_{ijd} = (X_{ijd} - \text{Min } X_{ijd}) / (\text{Max } X_{ijd} - \text{Min } X_{ijd})$,When observed values (X_{ijd}) are positively related to the vulnerability (e.g. higher the variation in rainfall, higher the vulnerability in exposure), and $Y_{ijd} = (\text{Max } X_{ijd} - X_{ijd}) / (\text{Max } X_{ijd} - \text{Min } X_{ijd})$, When the observed values (X_{ijd}) are negatively related to the vulnerability (e.g. higher productions of fish, lower the vulnerability in sensitivity). Finally, the VI of region/district is assumed to be a linear sum of VIs on major components.

Table 42. Vulnerability scores & explanations for selected districts of West Bengal

Districts	Vulnerability Score	Discussion /Explanations
24 Paraganas (S)	0.615	Fisheries activity in this coastal district of West Bengal is more exposed (0.17) of climatic events and adaptive capacity (0.27) is less in terms of limited opportunities for occupational diversification.
Murshidabad	0.552	For this district sensitivity (0.13) indicators are less vulnerable to climate change, though exposure (0.20) of climate change is very high and resilience (0.22) is too poor.
24 Paraganas (N)	0.549	In this district three components of vulnerability are at high level. The adaptive capacity (0.21) to climate change is very less than other two components and contributes more to overall index.
Nadia	0.527	Adaptive capacity (0.12) is less vulnerable i.e. very strong to climate change. But other two components sensitivity and exposure are at high level of vulnerability.
East Midnapore	0.5172	The adaptive capacity (0.15) is strong, but other two components in this coastal district are at high level.
North Dinajpur	0.5170	In the district of North Dinajpur, climatic variations and variation in production due to soil quality, tern to more vulnerable.
South Dinajpur	0.315	In this district, three components are at very low level in terms of less variation in fish production, climatic events such as rainfall, temperature, flood etc, and occupational options as measure of strong adaptive capacity.

The over all vulnerability score for South 24 Parganas was more (0.615) than all other districts of West Bengal, Where as the South Dinajpur stood last with smallest score 0.315. An overall analysis of the vulnerability scores on few selected districts leads to conclude that, in most of the districts, the exposure and adaptive capacity parameters are the drivers of the vulnerability, i.e. a districts having high exposure i.e. threaten by extreme climatic events on fisheries sector with high adaptive capacity or low resilience to that threat leads the district in high vulnerability index (Table 42).

Objective: Impact of cyclone Aila on fishing, aquaculture and fishers communities of Sundarbans in North 24 Parganas, West Bengal

North 24 Parganas district is a district in southern West Bengal, India. North 24 Parganas extends in the [tropical zone] from latitude 22º11´6´´ north to 23º15´2´´ north and from longitude 88º20´ east to 89º5´ east. The total geographical area is 4094.00 sq. kms with 3594.44 sq.kms rural and 499.56 sq.kms urban areas.

Agriculture and pisciculture area main source of livelihood in these areas the impact was maximum affecting the socioeconomics with loss to human lives, properties, fishing equipments, agriculture and aquaculture enterprises.

The study was conducted in 15 sites at village Chakpatli, Mahispukur, Ghuni, Barunghat-Katakhali, Kalutala, Tengramari & Taragopal in Hasnabad Block and Dulduli, Kalitala, Samsernagar, Sahebkhali, Lebukhali, Rupmari, Amberia, Hemnagar & Jogeshgang in Hingalganj Block of North 24 Parganas in Sundarban Delta (Fig.102).

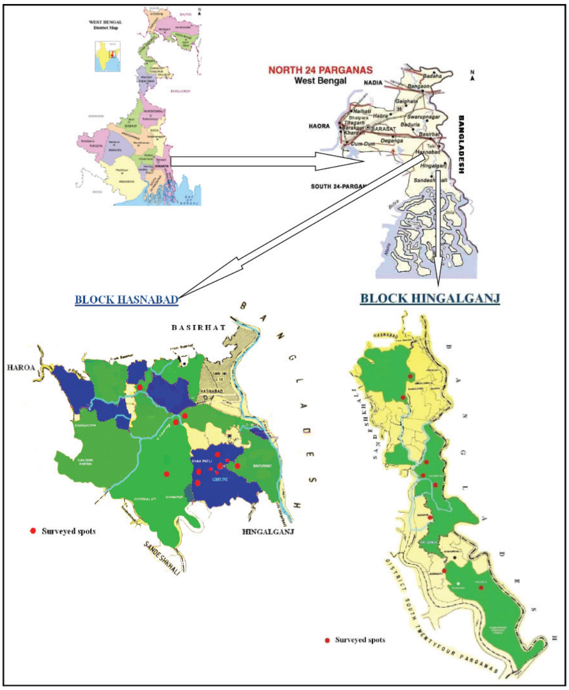


Fig.102. Location of the study areas/sites in Hasnabad & Hingolganj Block in 24 Parganas, West Bengal

Impact of Cyclone Aila on Pisciculture

As a result of the cyclone, a total of more than 70% people were either made homeless or had their livelihoods disrupted. Damages included loss of income, destruction to fish ponds, bheries and gear, as well as other assets.

Adaption measures adopted

1. Fishers were totally dependent on fishing and wild fish seeds collection from natural resources as the only source of income.
2. Due to ingressed saline water paddy fields got inundated became unfit for agriculture. These areas were temporarily converted into ponds for fish culture with saline tolerant fish species *viz., Mugil parsia, M. tade and Lates calcarifer*.

Impact of Aila on inland fishery resources

Study area: South 24-Parganas

Water resources of the district were delineated using IRS 1D PAN + LISSIII merged satellite data using supervised classification and visual interpretation. Mapping reveal that 1060 water bodies are in the district having area more then 0.5ha. Details of water bodies in table 43. Most of the water bodies are below 10 ha. Due to limitation of the image resolution imageries the water bodies having area below 0.5 can not delineated.

Table 43. No. of water bodies and their area in South 24-Parganas

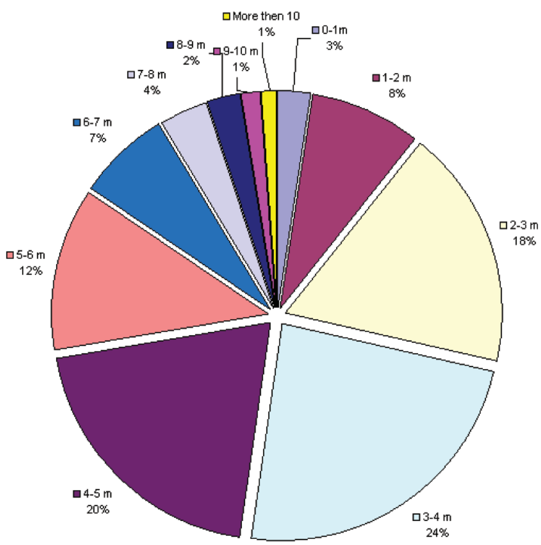
S. No.	Classes	Total			Perennial		
		Number	Max Area	Average Area	Number	Max Area	Average Area
1	0.5 to 10 ha	895	1899.5	1202.4	263	853.6	684.3
2	10 to 50 ha	107	2324.7	1585.6	76	1734.2	1290.5
3	50 to 500 ha	51	7553.4	5885.3	41	6523.6	5370.4
4	500 to 1000 ha	4	2457.4	1760.8	4	2457.4	1760.8
5	More than 1000 ha	3	4064.8	3113.5	3	4064.8	3113.5
	Total	1060	18299.8	13547.6	387	15633.6	12219.5

Impact assessment studies

To assess the impact of such cyclonic events like AILA on coastal areas of south 24 parganas Digital elevation Model was generated from SRTM (Shuttle Radar Topographical Mission) of 90m spatial resolution data. Contour lines were created with the help of TNT Mips software in meter. The extent of land that may be submerged under scenarios of sea water rise is given in table 44.

Table 44. Sea rise and extended of submerge

S.No.	Elevation in meter	Area in different elevation
1	0-1m	18464
2	1-2 m	58880
3	2-3 m	127178
4	3-4 m	169149
5	4-5 m	141835
6	5-6 m	87773
7	6-7 m	48635
8	7-8 m	27263
9	8-9 m	16980
10	9-10 m	10121
11	More then 10	7964



TAMILNADU AGRICULTURAL UNIVERSITY
COIMBATORE

Objective: Developing optimal land use pattern for different ACZs using the concept of different cropping systems followed in Tamil Nadu in current and future climate change scenarios

In 2008-09 an MGLP model for Tamil Nadu was developed for optimum land allocation under different climate change scenarios was developed. A software package for this purpose was also developed by this centre. Scientists from different networking centers were given training in using this software.

As suggested by the national coordinator, MGLP model incorporating cropping systems has been developed this year. A software written in MATLAB is also prepared. This software package was test verified with data for Haryana State provided by national coordinator.

For Tamil Nadu, the prevailing major cropping systems are now identified and the relavant data are collected and so the results of the MGLP model with cropping systems for Tamil Nadu will be taken up in the year 2010-11.

Objective: Documenting the weather related Indigenous Technical Knowledge (ITK)

Indigenous Knowledge is the actual knowledge of a given population that reflects the experience based on tradition and includes more recent experiences with modern technologies (Haverkort, 1995). Today, many indigenous knowledge systems are at risk of becoming extinct because of rapidly changing natural environments and fast pacing economic, political, and cultural changes on a global scale. Practices vanish, as they become inappropriate for new challenges or because they adapt too slowly. However, many practices disappear only because of the intrusion of foreign technologies or development concepts that promise short-term gains or solutions to problems without being capable of sustaining them. Hence, there is an immense pressure on the people of India, to collect, preserve, validate and adopt Indigenous agricultural practices (IAPs) so as to reduce dependence on external inputs, to reduce the cost of cultivation and to propagate eco-friendly agriculture (Sundamari and Ranganathan, 2003).

Some common indigenous knowledge used by the farmers of Tamil Nadu to rainfall, flood, temperature, lightning, drought occurrence and manage their farming are stated as follows. Indigenous knowledge plays a major role in finding location specific solutions for problems based on the land of the farm family, its microclimate, the access to land, inputs arid labour in different times of the year. Much of this knowledge is not based on formal research, but on careful observations and experience from the farm family, the parents, friends and colleagues. Since every technology has positive and negative effects, it is necessary to analyze the available ITK technologies carefully before recommending adoption by the farmers. This is true for both scientific and traditional knowledge. It may be necessary to refine or modify the modern technologies.

Objective: Assessing the magnitude of change in temperature and rainfall over Tamil Nadu region up to 2100

The précis A1B scenario data were extracted to assess the regional changes of Tamil Nadu in temperature in temperature and precipitation over 21st Century. The data set covers the baseline time period of 1961-1990, A1B Scenario for the period of 2021-2050 and 2071-2098.

In future climate scenario, all regions of the Tamil Nadu would experience significant and often different changes in rainfall and temperature extremes. As model run results more increase in minimum temperature than maximum temperature the occurrence of warm nights is projected to be more frequent. Significant changes in rainfall extremes and dry spells are also projected.

Objective: Assessing the phonological response of maize and sorghum to elevated temperature using temperature gradient tunnel

Rice crop was exposed to given elevated temperature levels *viz.,* 0.5, 1, 1.5, 2, 2.5, 3.0, 3.5, 4, 4.5 and 5 degree C using temperature gradient tunnel. Crop duration shortened was 1-3 days at 1.5 temperatures. The extend of crop duration decrease was (1-4 days) at 2.5°C. Pronounced shortening of duration (2-5 days) could be observed at 4.5 increases in temperature. The days to anthesis was advanced by 1 to 3 days with 1.5°C increase in temperature and the days taken to anthesis decreased (3-5 days) with increase temperature from 3.5°C. There is a significant impact (-25%) on due to elevated temperature on economic yield. This decrease was more significant from 3.0 – 5°C. LAI also decreased when temperature reaches 3.5°C. Dry matter production showed a decrease with increasing temperature and the decrease was quite high (13%) while temperature raises to 3.5 -5°C. The number of grains m^{-2} at 1.5 -2.5°C ranged from 222972848 – 254755309. But at 2.5 – 5°C increase in temperature grain number declined at great level of 201973051.

DSSAT model was employed to study the physiological response of maize and sorghum to elevated temperature. The reduction in modeled maize yields is primarily attributed to temperature increases that shorten the crop growth period, particularly the grain-filling period. The projections showed that the production changing negatively from mean yield for maize and sorghum were 4.2 – 25.8 % and 3.5–14%, respectively for increase in temperature from 1°C to 5°C.

Model simulation suggest that C_4 photosynthesis (Maize and sorghum) is already saturated at the current levels of atmospheric CO_2, and future increases in CO_2 (550 ppm) will not be effective at boosting productivity.

Objective: Mapping the hydrology of major river basins of Tamil Nadu for changing climate

SWAT model for the Cauvery River Basin in Tamil Nadu, India to assess the hydrological situations, crop water requirement and crop yield. SWAT model runs on the GIS platform and divides the entire watershed into smaller sub-basins based on the digital elevation map of the study area (Fig. 103). Each sub-basin is further divided into many homogenous hydrological response units (HRUs) based on the inputs such as soil, slope and land use to represent the natural hydrologic system.

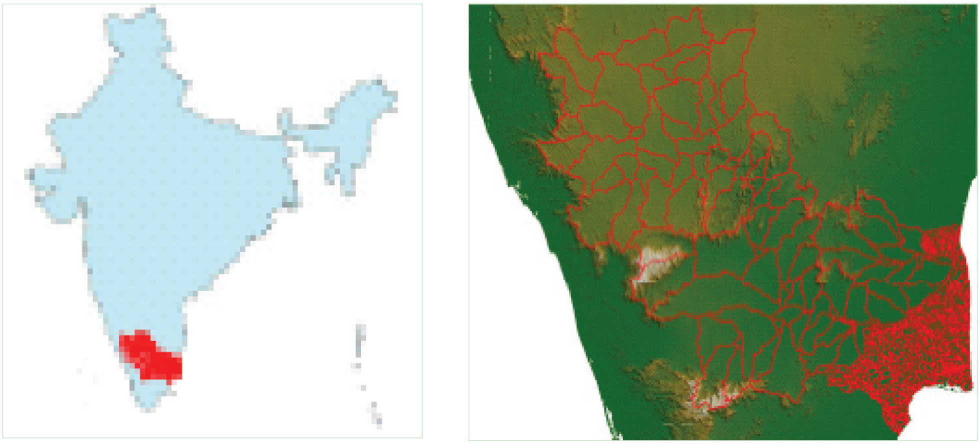


Fig.103. Digital Elevation Model (SRTM) and Watershed delineation

Information on soil was based on the soil map at 1: 50,000 scale obtained from the Remote Sensing Unit of Tamil Nadu Agricultural University. Though cauvery basin has a variety of soils, majority of the area has sandy clay loam and sandy loam soils. Sizable area also represents sandy clay and clay soils. Slope of the Cauvery river basin was broadly divided into three classes *viz.,* 0-1%, 1-2% and >3% (Fig.104).

Land use data was obtained from ISRO, Bangalore (Fig. 105). In the Cauvery basin 77.8% of the area is covered by Rice crop. A Rice fallow pulse occupies 9% of the area and forest cover is only 8.5%. Marginal area is occupied by corn, cotton, grain sorghum and other crops. Most of the rice crop is grown in the slope between 0 – 3% and forest occupies most of the high sloppy lands.

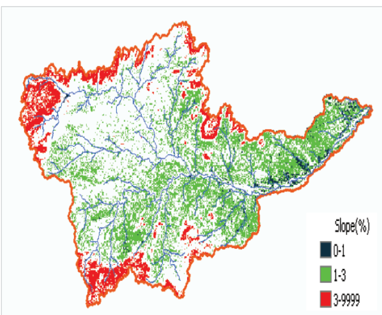


Fig.104. Slope of Cauvery River Basin

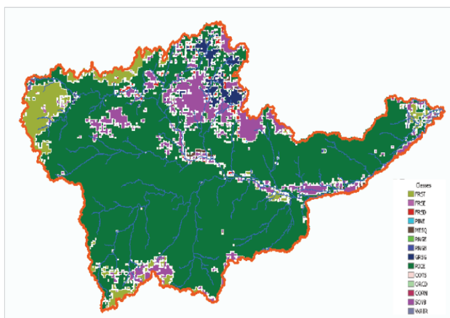


Fig.105. Land use Map of Cauvery River Basin

SWAT Model simulated Hydrological components for Cauvery Basin in Tamil Nadu

Annual summary of hydrological components of Cauvery River basin for the current situation as simulated by SWAT model is presented in Table 1, except rainfall which the actual is observed mean data for the basin as a whole.

Thirty years mean annual precipitation in the Cauvery basin is 1128.67 mm. However, within the basin lot of variation is observed in terms of both quantum as well as distribution (Table 45).

Table 45. Annual summary of hydrological components of Cauvery River basin

Particulars	Amount in mm
Rainfall (Observed)	1128.67
Surface flow	188.90
Lateral Flow	15.57
Ground water	152.14
Percolation	212.64
Soil water	786.12
ET	704.62
PET	2195.73

Mean monthly distribution of precipitation, soil water storage and Evapo-transpiration and Potential Evapo transpiration for the Cauvery basin is presented in the table 46.

Cauvery basin receives major share of its rainfall during North East Monsoon (44.44 %) followed by South West Monsoon seasons (36.18 %). The atmospheric demand for the moisture (PET) is maximum during summer season. Only around 50 % of the annual PET is met from the rainfall.

Table 46. Monthly distribution of rainfall, Soil water, ET and PET of Cauvery River basin

Month	Rainfall	ET	PET
	(mm)	(mm)	(mm)
Jan	65.06	29.6	187.90
Feb	38.69	33.8	176.29
Mar	28.82	45.19	208.27
Apr	32.48	53.9	202.50
May	53.59	74.65	227.21
Jun	75.21	61.12	167.90
Jul	95.01	57.08	149.86
Aug	98.51	60.76	179.17
Sep	139.66	68.27	173.67
Oct	191.91	88.33	196.25
Nov	179.43	75.14	166.91
Dec	130.29	56.78	159.80
Annual	1128.67	704.62	2195.73

SWAT Model simulated Sediment yield in Cauvery Basin in Tamil Nadu

Due to the surface flow, the top nutrient rich soil gets eroded and goes away from the sub basins. Monthly surface flow, water yield and sediment yield from the entire Cauvery basin are presented in Table 47.

From the Cauvery basin every year 5.5 tonnes of sediment from one hectare of land is taken away due to surface flow. Major erosion occurs from the high sloppy land which has more than 3% slope.

Table 47. Surface flow, water yield and Sediment yield from Cauvery basin

Month	Surface Flow (mm)	Water yield (mm)	Sediment Yield (t/ha)
Jan	9.14	9.71	0.66
Feb	19.06	24.26	0.99
Mar	17.69	29.13	0.64
Apr	6.03	16.43	0.24
May	15.99	25.42	0.5
Jun	11.07	21.1	0.38
Jul	11.74	23.84	0.14
Aug	15.61	30.96	0.24
Sep	19.90	38.82	0.34
Oct	19.37	40.99	0.47
Nov	19.04	42.48	0.36
Dec	24.91	51.93	0.53
Annual	188.90	354.25	5.50

Objective: Comparison on Rice Cultivation Systems for methane emission

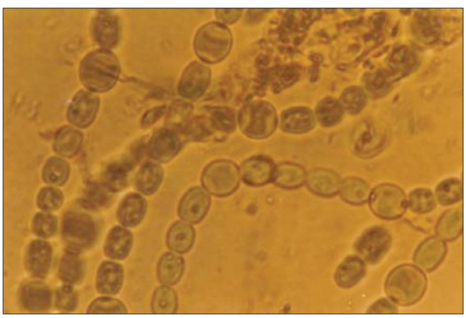
Owing to increasing water scarcity, a shifting trend towards less water demanding crops against rice is noticed in most part of the India and this warrants alternate methods of rice cultivation that aims at higher water and crop productivity. There are evidences that cultivation of rice through system of rice intensification (SRI) can increase rice yields by two to three fold compared to current yield levels. Aerobic rice cultivation where fields remain unsaturated throughout the season like an upland crop offers an opportunity to produce rice with less water. More interestingly the SRI and aerobic rice systems emit less methane due to increased soil redox as a result of alternate wetting and drying being followed in the cultivation period. In this context, a study was conducted at wetland farm of Tamil Nadu Agricultural University, Coimbatore to evaluate the performance of different systems of rice cultivation in terms of its water use efficiency, grain productivity and methane emission rates. Treatments consisted of different rice cultivation methods viz., transplanted rice (conventional), direct sown rice (wet seeded), alternate wetting and drying method (AWD)(irrigation at once in three days), system of rice intensification (SRI) and aerobic rice cultivation.

In both summer and *Kharif* seasons, system of rice cultivation (SRI) produced higher grain yield (6014 and 6682 kg/ha), followed by transplanted rice (5732 and 6262 kg/ha) while, the lowest grain yield (3582 and 3933 kg/ha) was recorded under aerobic rice cultivation. Under SRI, 5 and 6.7 % increase in grain yield and 12.6 and 14.8 % water saving were noticed compared to transplanted rice respectively during summer and kharif seasons. With respect to water productivity, SRI method of rice cultivation registered the highest water productivity (0.43 and 0.47 kg/m^3), followed by AWD and aerobic rice cultivation. The conventional rice cultivation and direct sown rice produced lower grain yield per unit quantity of water used. While estimating the methane evolution from the different systems of rice cultivation aerobic, SRI and AWD recorded lowest emission rates (7.40. 7.80 and 7.95 mg CH_4 $m^{-2}h^{-1}$ respectively) while the emission rate was high in conventional system (8.80 mg CH_4 $m^{-2}h^{-1}$).

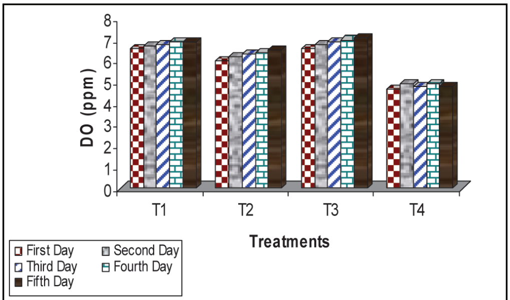
Redox status of a flooded soil is an indirect indicator of methane flux pattern from rice ecosystem. Methane production is negatively correlated with soil redox potential and positively correlated with soil temperature, soil carbon content, and rice growth. Methane is exclusively produced by methanogenic bacteria that can metabolize only in the strict absence of free oxygen and at redox potentials of less than -150 mV. As SRI, aerobic rice and AWD facilitated more oxygen diffusion due to periodical drying; the redox potential was high leading to less methane emission. Hence the system of rice intensification (SRI) can be promoted as ecofriendly rice cultivation system due to its higher water use efficiency and yield potential besides emitting less methane.

Objective: Developing mitigation methodologies to minimize methane evolution from flooded paddy

Recently, it has been reported that growing Cyanobacteria and Azolla in rice fields could reduce global warming potential. Therefore, it is important to collect more information on the role of Blue green algae and Azolla on green house gas emission from rice soils. This study gives evidence that Blue green algal systems could reduce global warming potential from flooded rice soils at the levels of green house gas production, transport and oxidation. The present study was aimed to find out the role of these biofertilizers as a dual crop in indirectly minimizing global warming potential from flooded paddy apart from their ability to supply nitrogen to the paddy crop. A field experiment was carried out at Tamil Nadu Agricultural University, Coimbatore, India to find out the difference in global warming potential from rice field while using photosynthetic systems such as Azolla and Cyanobacteria.



Microphotograph of blue green algae, *Nostoc muscorum*



Influence of algae and azola on dissolved oxygen (ppm) content of rice field under conventional system (Reading taken at the stage of flowering)

The global warming potential from the rice soil microcosms was determined by continuous analysis of dissolved oxygen content for one week during flowering period and redox potential during whole crop growth period.

The Azolla and Cyanobacteria systems in combination indirectly minimized the global warming potential in flooded paddy which was identified based on dissolved oxygen and redox potential measurement. The dissolved oxygen content of the water impounded in Azolla and Cyanobacteria fields was found to be higher than the control plot. The combination of Azolla and cyanobacterial systems were recorded a dissolved oxygen content of 7.4 ppm as against 4.3 ppm in the uninoculated plot. Cyanobacteria and Azolla that grow on the soil surface and also as a floating mass acts as live aerators in paddy field ecosystem and oxygen released during the photosynthetic activity got liberated as minute air bubbles and consequently aerate the water impounded in paddy field that resulted in increased dissolved oxygen content which ultimately decreased the methane flux. Redox status of a flooded soil is an indirect indicator of methane flux pattern from rice ecosystem. Methane production is negatively correlated with soil redox potential and positively correlated with soil temperature, soil carbon content, and rice growth. Methane is exclusively produced by methanogenic bacteria that can metabolize only in the strict absence of free oxygen and at redox potentials of less than -150 mV.

The application of Cyanobacteria and Azolla resulted in higher redox potential under flooded condition. In the present investigation, the combination of Azolla and cyanobacterial systems recorded a redox content of 252 mV as against -43 mV in the uninoculated plot during flowering. Eh affects not only methanogens but also gas transfer through the plant. At lower Eh, aerenchyma formation increased and the size of the roots decreased. A decrease in Eh from -200 to -300 mV induced a tenfold increase in methane production and a 17 fold increase in its emission.

BIDHAN CHANDRA KRISHI VISWAVIDYALAYA
MOHANPUR

Objective: To collect information on climate change related ITK and conducting Farmers' Awareness Programme

The climate change related ITK was collected through consultation with the farming community and feedback survey. A brief report on ITK was sent to the co-ordinating cell at IARI, New Delhi.

For generating awareness among the farmers on climate change, an awareness programme was conducted by the centre (Plate 1 and 2) in which 60 farmers participated and the following lectures were given:

1. Causes of climate change
2. Overall impact of climate change
3. Impact of climate change on crops
4. Impact of climate change on pest-diseases
5. What we should do to combat climate change

Objective: The climatic trend analysis for different stations under different agro-climatic regions of West Bengal

Baharampur which belongs to New Alluvial Zone of West Bengal showed a gradual decreasing trend of maximum temperature of summer months and it ranged between 36.8 and 42.3^{O}C since last 65 years (1942-2007) (Fig.106). In case of minimum temperature (winter months) the trend is quite reverse but the degree of increase is less steep. Through out the period (1942-2007) the magnitude of minimum temperature varied between 9 to 18.7 ^{O}C (Fig.107). The oscillation of maximum temperature from its normal value was noticeable. Generally it ranged from +6 to -5.5 ^{O}C. It was observed that after 1974, during most of the year the oscillation occurred in positive direction (Fig.108). In case of minimum temperature the deviation from its normal value ranged between 4.4 to -5.3 ^{O}C and year wise such variation did not followed any specific pattern (Fig.109).Total annual rainfall distribution showed a gradual increasing trend. The maximum and minimum rainfall was recorded 2290 mm and 653 mm, respectively during the above mentioned period (Fig.110). The average annual rainfall of this station is 1363 mm.

The database from 1952 to 1976 was analyzed for Burdwan station. It was observed that in general maximum temperature showed an increasing trend with very small amount (0.085 ^{O}C) of temperature increment per year. However, the magnitude of temperature was in between 33 to 41.1 °C (Fig.111).

Canning is one of the representating stations of Coastal and Saline zone of West Bengal. The total annual rainfall of this station was collected from 1959 to 2003. The annual average rainfall of this region is 2114 mm (Fig.112). It was observed that the amount of rainfall increase gradually with progress of year. The increment was highly remarkable during 1975 to 1990. During this period almost all year's rainfall amount was higher than the normal value. However after 1990 the rainfall amount decreased drastically and became at par with nineteen fifties database.

Jalpaiguri which belongs to Terai agro-climatic zone of West Bengal showed a gradual and very slow increasing trend of maximum temperature and its value remained in the range of 28.5 to 35.2°C since last 45 years (1942-1987). The rate of increase of maximum temperature was to the tune of 0.04 °C per year (Fig.113). The minimum temperature showed a slight decreasing trend (Fig.114). Through out the period (1942-1987) the magnitude of minimum temperature varied between 7 to 31°C. So there is a wide range of winter minimum temperature in this region. Total annual rainfall distribution showed a gradual decreasing trend. During 1974 the highest rainfall (4342 mm) was received by this region and the minimum was recorded in the year 1986. The average annual rainfall of this station is 3242 mm (Fig. 115).

Kalimpong belongs to Hill zone of West Bengal showed a gradual and very slow increasing trend of both maximum and minimum temperature. The magnitude of maximum temperature remained in the range of 19.0 to 30.9°C since 1942 to1991. The rate of increase of maximum temperature was to the tune of 0.03 °C per year (Fig.116). An abrupt oscillation of maximum temperature in both directions was noticed after 1977. Through out the period (1942-1991) the magnitude of minimum temperature varied between 5.1 to 14.2 °C (Fig. 117). Total annual rainfall distribution showed a gradual decreasing trend. During 1984 the highest rainfall (3441 mm) was received by this region and the minimum was recorded in the year 1981. The average annual rainfall of this station is 2207 mm. (Fig.118). Like maximum temperature the total annual rainfall distribution pattern showed abrupt changes in both higher and lower sides.

Malda is a station located in Old Alluvial Zone of West Bengal. The maximum, minimum temperature and rainfall data were analyzed for the year 1942 to 1991. All the three parameters showed increasing trend (Fig.119 - 121). However, the change of maximum temperature is negligible (+0.004 °C/year). The minimum temperature increased with a rate of 0.05 °C/year. The annual average rainfall of this station is 1371 mm. During 1987 the highest rainfall (2341 mm) was received by this region and the minimum (616 mm) was recorded in the year 1979. After 1970 the annual total rainfall change was quite remarkable by both in magnitude and oscillation.

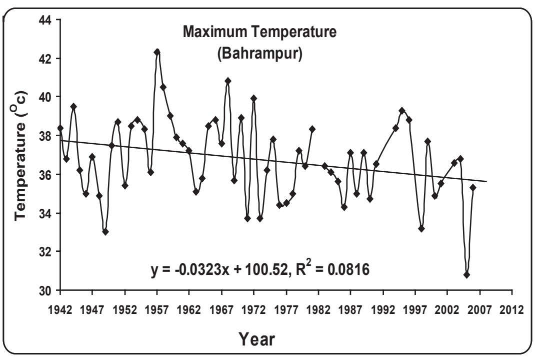


Fig.106. Variation of maximum temperature of summer months in Baharampur station

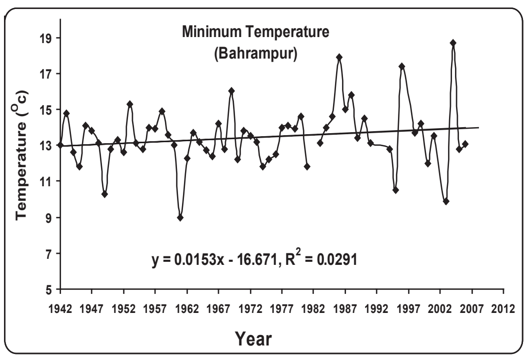


Fig. 107. Variation of minimum temperature of winter months in Baharampur station

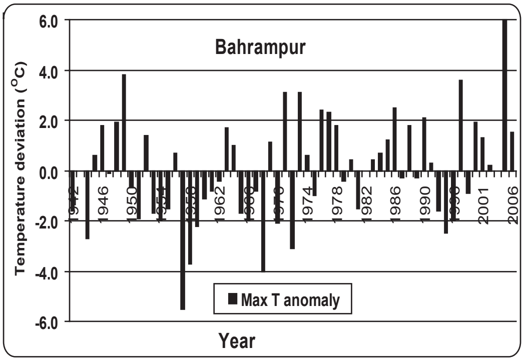


Fig.108. Deviation of maximum temperature from the long term normal value

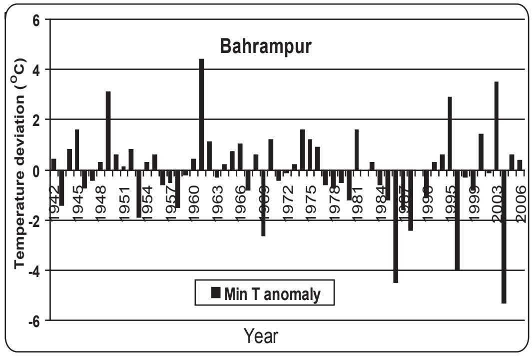


Fig.109. Deviation of minimum temperature from the long term normal value

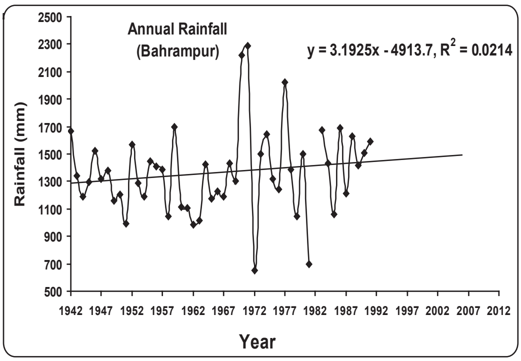


Fig.110. Variation of annual rainfall in Baharampur station

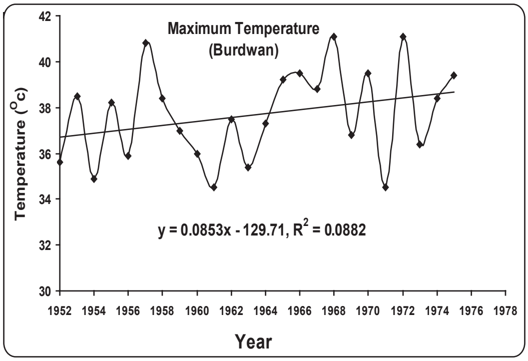


Fig.111. Variation of maximum temperature of summer months in Burdwan station

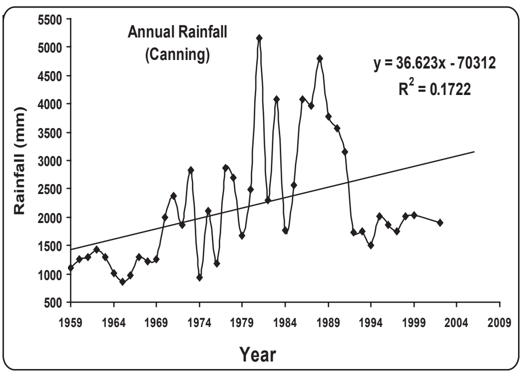


Fig.112. Variation of annual rainfall in Canning station

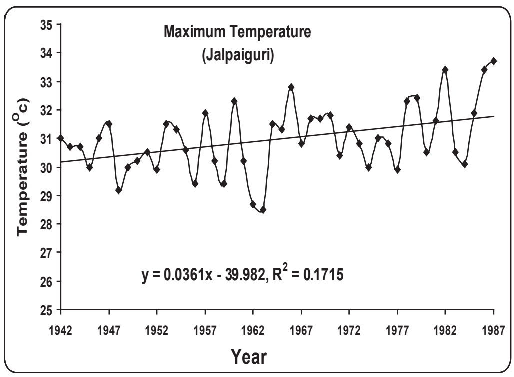


Fig.113. Variation of maximum temperature of summer months in Jalpaiguri station

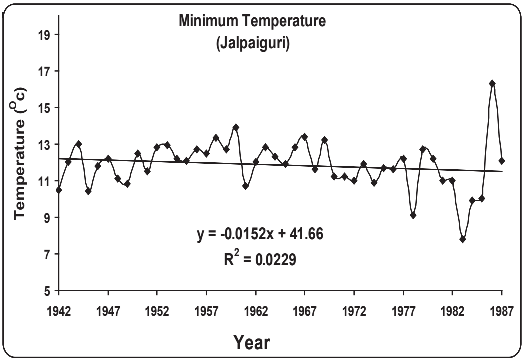


Fig.114. Variation of minimum temperature of summer months in Jalpaiguri station

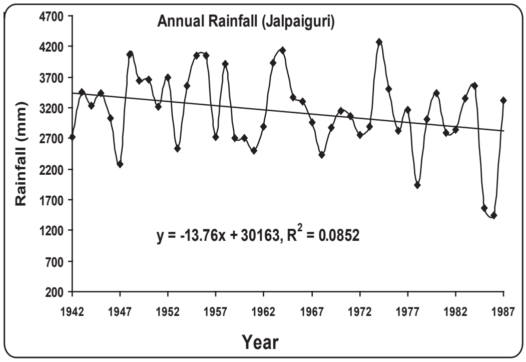


Fig.115. Variation of annual rainfall in Jalpaiguri station

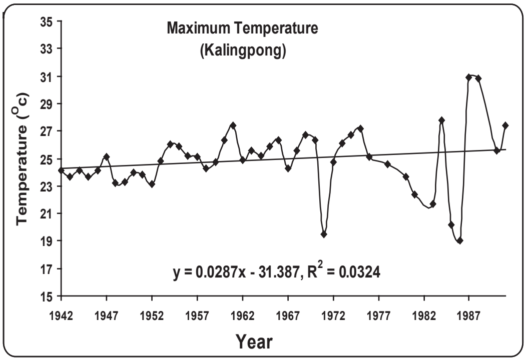


Fig.116. Variation of maximum temperature of summer months in Kalimpong station

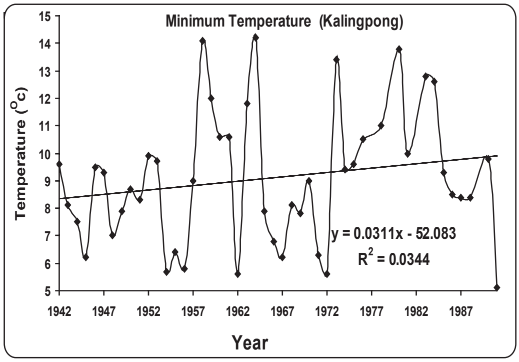


Fig.117. Variation of minimum temperature of summer months in Kalimpong station

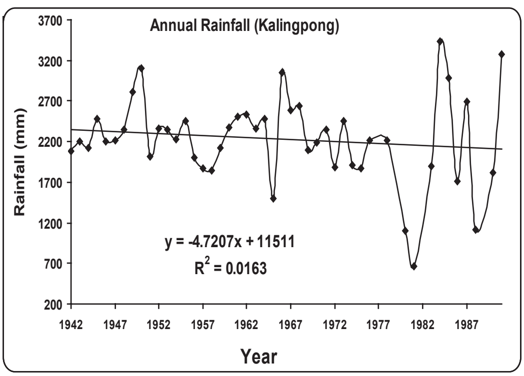


Fig.118. Variation of annual rainfall in Kalimpong station

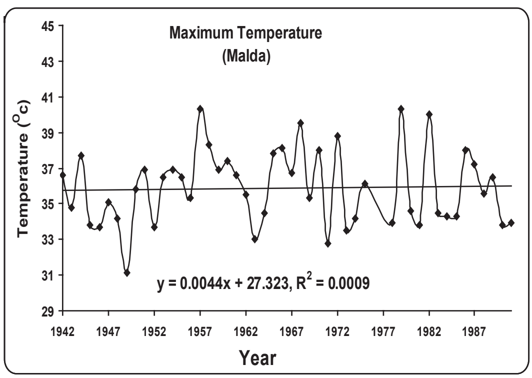


Fig.119. Variation of maximum temperature of summer months in Malda station

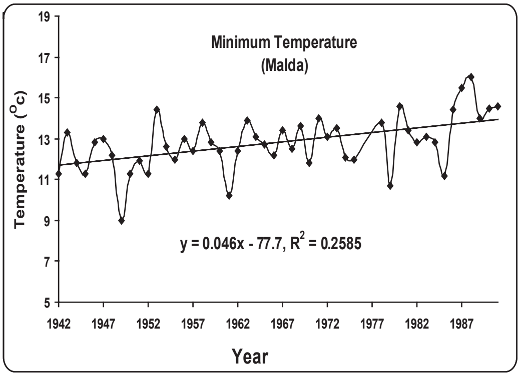


Fig.120. Variation of minimum temperature of summer months in Malda station

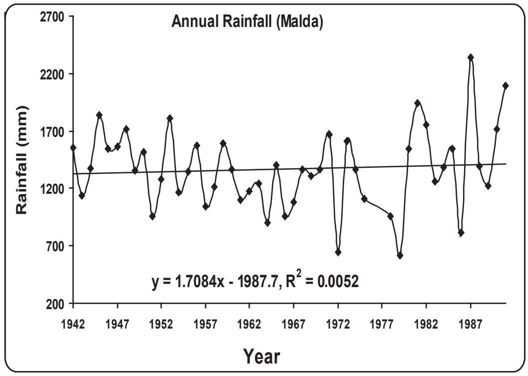


Fig.121. Variation of annual rainfall in Malda station

Objective: To find out the impact of climate change on growth and yield of *Kharif* rice, mustard and wheat

The Info-crop model has been used to detect the impact of climate change on the stated crops. As 2009-10 is the beginning year of the project, the study was conducted in the New Alluvial zone of West Bengal only due to availability of crop management data of this zone. Meanwhile, the required dataset for other agroecological zone is under collection. The weather data of Kalyani observatory (2000-2008) were uploaded in the Info-crop model (using weather converter) and the soil characteristics, different crop management practices followed in the zone were incorporated in the model.

The potential yield of Ratna variety of rice was observed if the crop is sown on 1st June (Table 48). The potential yield is decreased by 300 kg/ha if it is sown in end of June. If the temperature (both maximum and minimum) is increased by 1ºC, the potential yield is decreased by 830 kg/ha. The rainfall situation for the future assumes to be same as the present scenario because in case of determining potential yield it is considered that there is no limitation of water and nutrients. In general, the days required for maturity of the said rice variety is 109 days whereas due to increase in temperature it will mature within 107 days.

Likewise, the yield reduction of mustard (var. *Rohini*) and wheat (var. *Sonalika*) are in the tune of 450 kg/ha and 640 kg/ha respectively for increase in 1^{0}C of temperature (both maximum and minimum). Due to temperature increase, maturity period for both the crops will decrease.

Table 48. Potential yield (in case of temperature rise by 1^0 C) of *Kharif* rice

Crops	Potential yield		Maturity period	
	Normal condition	+1^{0}C rise	Average	+1^{0}C rise
Kharif rice	5190.4*	4360	109	107
Mustard	1714*	1277.7	93	88
Wheat	3884*	3248.6	94	89

* Yield data are average of 2000 to 2008

Objective: To work out the adaptation strategies in view of climate change

In case of rice, the model output shows that if older seedlings (about 25 days old) are transplanted (in case of +1^{0}C rise in temperature) the yield is further reduced. It may be due to the fact that increase of temperature hastens the physiological processes of the plant and the older seedling faces problems in tillering after transplanting operation. Moreover the optimum sowing time should be end of May (Table 49).

Generally in Gangetic West Bengal the mustard is sown during mid October. But simulation under temperature rise condition shows the November sown crop gives better result. Similar result has been observed in case of Wheat also. Late November sown crop shows higher yield than early sown crop.

Table 49. Yield of *Kharif* rice at two dates of transplanting

Age of seedlings (days)	23rd May	1st June	8th June	15th June	30th June
18	4712.5	4267	4347	4142.2	4331.5
25	4359.1	4098.45	3906.7	3794.75	4385.6

NATIONAL BUREAU OF SOIL SURVEY AND LAND USE PLANNING

NAGPUR

Objective: Identify and use data sets in the Benchmark (BM) soils and in the LTFT (Long Term Fertilizer Trial) sites to estimate and predict carbon reserves

The following BM spots and LTFT were selected. The datasets were compiled in terms of soils, land use, crop management and climate (Table 50).

Table 50. Details of soil and crops

S. No.	B M spots	Soil series	Crops
1	Bhopal	Nabibagh	Soyabean-Wheat
2	Jabalpur	Kheri	Rice, Wheat
3	Raipur	Raipur	Rice, Wheat
4	Parbhani	Kesapur	Cotton, Wheat, Soybean
5	Akola	Paral	Cotton, Soybean
6	Hyderabad	Kasireddipalli	Gram, Sorghum, Pigeonpea
7	Banglore	Vijapura	Pearlmillet, Pigeonpea
8	Kovilpatti	Kovilpatti	Cotton, Maize, Pearlmillet
9	Coimbatore	Palathurai	Cotton, Maize
10	Junagadh	Semla	Cotton, Groundnut, Wheat
11	Udaipur	Udaipur	Pearlmillet, Mustard

An example of datasets is shown for Kheri spot

Kheri series, Jabalpur (M.P.)

Description of soil series

The Kheri series is a member of the very fine, smectitic, hyperthermic family of Typic Haplusterts. Typically, Kheri soils have dark greyish brown to very dark greyish brown, neutral, clay A horizons, and very dark greyish brown, neutral to moderately alkaline and clay B horizons.

Landuse:

Cultivated to rice, wheat, gram, linseed, pigeonpea and lentil; natural vegetation -*Acacia spp.* (babul), *Butea spp.* (palas), *Annona spp.* (custard apple) and grasses *Cynodon spp.* (dhub), *Saccharum spp.* (kans), etc.

LTFE, climate and soil data:

The LTFT, climate and soil data of Kheri series are presented in tables 51, 52 and 53.

Table 51. Climate datasets: Average of 55 years (1951-2005)

	Rainfall	T Max	T Min	MAT	Rainfall	PET	1/2 PET
	(mm)	ºC	ºC	ºC	(cm)	mm)	(mm)
Jan	20.69	25.46	10.14	17.80	2.07	69.6	34.80
Feb	21.80	28.69	12.61	20.65	2.18	88.8	44.40
Mar	16.11	33.90	17.05	25.48	1.61	134.9	67.45
Apr	5.44	38.92	22.37	30.64	0.54	165	82.50
May	12.44	41.61	26.69	34.15	1.24	203.2	101.60
Jun	175.42	37.81	26.65	32.23	17.54	172.6	86.30
Jul	367.23	31.24	24.35	27.79	36.72	105.8	52.90
Aug	424.48	29.79	23.77	26.78	42.45	99.3	49.65
Sep	187.69	31.26	23.36	27.31	18.77	107.4	53.70
Oct	32.47	32.03	19.57	25.80	3.25	112.7	56.35
Nov	10.95	29.40	13.72	21.56	1.09	78.3	39.15
Dec	10.60	26.33	10.07	18.20	1.06	63.2	31.60

Table 52. LTFT datasets

Fertilizer Treatments	Crop	Inorganic fertilizer applied (kg/ha)	Organic manure applied (t/ha)	Soil organic carbon (%)
T1 = Control	Soybean Wheat Fallow	Plots did not receive NPK fertilizers and FYM	0	0.61
T2 = 50% NPK	Soybean	N:P:K=60:40:20	0	0.70
	Wheat	N:P:K=10:40:10		
	Fallow			
T3 = 100% NPK (recommended)	Soybean	N:P:K=120:80:40	0	0.80
	Wheat	N:P:K=20:80:20		
	Fallow			
T4 = 100% NPK + Hand Weeding	Soybean	N:P:K=120:80:40	0	0.72
	Wheat	N:P:K=20:80:20		
	Fallow			
T5 = 100% NPK + FYM	Soybean	N:P:K=120:80:40	15 t ha^{-1}	0.96
	Wheat	N:P:K=20:80:20		
	Fallow			

Table 53. Detailed soil datasets

Horizon	Depth (cm)	Size class and particle diameter (mm)									
		Total			Sand					Clay	
		Sand (2-0.05)	Silt (0.05-0.002)	Clay (<0.002)	Very coarse (2-1)	Coarse (1-0.5)	Medium (0.5-0.25)	Fine (0.25-0.1)	Very fine (0.1-0.05)	(0.002-0.001)	(<0.001)
		<-- % of < 2 mm -------------------------->									
Ap	0-15	13.6	22.9	63.5	2.1	1.4	1.6	3.5	5.0	15.2	48.3
A	15-37	15.9	22.3	61.8	-	0.5	1.3	1.8	12.3	18.3	43.5
Bss1	37-60	16.3	19.8	63.9	-	-	1.1	5.7	9.5	12.6	51.3
Bss2	60-84	17.3	19.1	63.6	-	-	1.3	6.0	10.0	7.4	56.2
Bss3	84-129	15.1	20.5	64.4	0.2	1.3	1.0	2.1	10.5	8.4	56.0
BC	129-150	13.7	20.6	65.7	-	-	1.0	1.7	11.0	9.6	56.1

Depth (cm)	Organic Carbon	$CaCO_3$ < 2 mm	pH (1:2.5) H_2O	Bulk density	COLE	Micronutrients			
						D T P A extractable			
						Zn	Cu	Mn	Fe
	%	%		Mg m^{-3}		<------------- ppm ------------>			
0-15	0.52	Tr	7.1	1.67	0.10	0.47	3.59	46	25
15-37	0.30	Tr	7.3	2.04	0.13	0.22	1.43	7	12
37-60	0.28	Tr	7.4	1.97	0.14	0.21	1.48	6	12
60-84	0.26	Tr	7.3	1.96	0.14	0.28	1.42	5	11
84-129	0.25	7.9	8.0	1.94	0.14	0.40	1.51	6	11
129-150	0.26	4.7	8.1	2.07	0.11				

Objective : To update soil information for InfoCrop and soil carbon models

A total of 131 soil series (two soil series for each AESR and 11 bench mark spots from ICAR network project on climate change) were compiled for updating the soil information for usage in InfoCrop and soil carbon models. These soils are Ladakh II, Ladakh III, Kibber, Chirai, Dune, Amiliara, Balasar, Hisar, Chandawal, Bhola, Semla, Jamkhandi, Sollapuram, Zarifa Viran, Shergarh, Baland, Kaljodiya, Nagariya, Bijaipur, Haripur, Singpura, Gondal, Kagwad, Haldhar, Jalalpur, Khuntwada, Lilvan, Talegaon, Sirasgaon, Torkewadi, Jambha, Loni, Achmati, Nimone, Rayadurg, Kurnool, Kasireddipalli, Chitkul, Cuddapah, Nuzvid, Coimbatore, Plalathurai, Aisandra, Channasandra,Sivagangai, Salur, Berpura, Shahazadpur, Basiaram, Sarthua, Bamori, Bartuma, Linga, Sukali, Bishramganj, Marha, Sagar, Gondatola, Mohranga, Hitekusa, Gadchiroli, Bawanpuri, Bhubaneswar, Motto, Pusaro, Ranga, Baratol, Hirapatti, Bahraich, Kesarganj, Bathal, Kalpa, Ropri, Dehra, Mataur, Rajpura, Gajeli, Tayari, Haldi, Nainital, Amarpur, Anantpur, Morigaon, Barbhagia, Bongaigaon, Sonari, Amguri, Darrang, Dhansiri, Reyong, Maniram, Longsom, Wakka, Mawlyndair, Lailad, Longol-5, Longol-6, Kalathur, Thirunallar, Kovvur, Kaveli, Srikakulam, Suryapet, Ratrapur, Sagar, PAti, Tinodas, Chimpukkad, Karingathode, Palghar, Virtha, Basanthipur, Govindpur, Kavaratti and Andrott. Since in most cases the data on soil parameters like saturation fraction, field capacity fraction, saturated hydraulic conductivity, and bulk density were not available. So they were evaluated using existing pedo-transfer functions. The data for the selected soil series were categorised into horizons of depths of 0-50, 50-100, 100-150 cm by the method of weighted average (Table 54).

Table 54. Depthwise calculation for Soil Master benchmark spots of climate change project-Kheri (Jabalpur) and Nabibagh (Bhopal), Madhya Pradesh, India

Soil Parameters		Nabibagh			Kheri		
		Soil Depth (cm)					
		0-50	50-100	100-150	0-50	50-100	100-150
Physical	Sand (%)	1.90	1.80	1.70	17.17	11.54	15.84
	Silt (%)	47.10	43.50	43.70	32.52	38.98	38.36
	Clay (%)	51.00	54.70	54.60	50.31	49.47	45.79
	Saturation Fraction	0.59	0.58	0.58	0.50	0.60	0.51
	Field Capacity Fraction	0.28	0.28	0.30	0.25	0.33	0.29
	Wilting Point Fraction	0.13	0.14	0.15	0.15	0.18	0.15
	Saturated HC (mm/day)	510.72	467.52	327.36	621.12	466.08	356.16
	Bulk Density (Mg m^{-3})	1.50	1.50	1.44	1.40	1.44	1.50
Chemical	Organic Carbon (%)	0.62	0.48	0.48	0.58	0.51	0.48
	Water pH		7.95			7.70	
	EC (dS m^{-1})		0.27			0.26	
Other (site)	Slope (%)		2.00			2.00	

Salient Findings of InfoCrop model

After the input of the necessary soil and weather data the InfoCrop model was executed to simulate the yield of soybean and wheat for Kheri and Nabibagh, to assess the probable impact of perchance impending climate change articulated by increased temperature and atmospheric carbon dioxide concentration on the yield with water availability as the sole limiting factor (Table 55 and 56).

The average simulated yield of soybean was 1610, 1599, 1777and 1928 kg ha^{-1} for Kheri in the first, second, third, and fourth scenario respectively. For Nabibagh the average simulated yield of soybean was 1773, 1750, 1909, and 2066 kg ha^{-1} for the first, second and third scenario respectively.

The average simulated yield of wheat was 6094, 6026, 6509, and 6701 kg ha^{-1} for Kheri in the first, second, third, and fourth scenario respectively. For Nabibagh the average simulated yield of wheat was 5683, 5652, 6103, and 6153 kg ha^{-1} for the first, second and third scenario respectively.

From the model output it is observed that sole increase in temperature results in decline in the yield of soybean and wheat when compared with a situation assuming business as usual. But when the increase in temperature is coupled with increased concentration of carbon dioxide there is significant improvement in soybean and wheat yield.

Table 55. Simulated soybean yield (1986-1995) for Kheri and Nabibagh under rainfed condition with water stress

	Station	T1[a]	T2[b]	T3[c]	T4[d]
Average Yield (kg/ha)	Kheri	1610	1599	1777	1928
	Nabibagh	1773	1750	1909	2066

[a]T1-No climate change; [b]T2- Rise in daily maximum and minimum temperature by 0.25$^{°C}$(a); [c]T3- (a) and carbon dioxide concentration to 450ppm; [d]T4- (a) and carbon dioxide concentration to 550ppm

Table 56. Simulated wheat yield (1985-1994) for Kheri and Nabibagh under irrigated condition with water stress

	Station	T1[a]	T2[b]	T3[c]	T4[d]
Average Yield (kg/ha)	Kheri	6094	6026	6509	6701
	Nabibagh	5683	5652	6103	6153

[a]T1-No climate change; [b]T2- Rise in daily minimum temperature by 0.25$^{°C}$(a); [c]T3- (a) and carbon dioxide concentration to 450ppm; [d]T4- (a)and carbon dioxide concentration to 550ppm

Compendium (ITK)

Data from 1532 farmers from 28 districts covering 9 states (Table 57) was collected and compiled. Perception of farmers regarding attributes of climate change, signatures of climate change and common methods of combating climatic aberrations were compiled. Preliminary analysis indicated that perceptions regarding climate change remained similar among them but the strategies to combat drought differed considerably across regions.

Table 57. Details on the number of respondents and districts covered*

State	Districts	Number of farmers
Punjab	Bhatinda, Ferozepur, Muktsar, Faridkot, Barnala, Mansa	300
Haryana	Sirsa, Hisar, Fatehabad	104
Gujarat	Narmada, Bharuch, Surat, Tapi,	50
Madhya Pradesh	Khandwa, Chhindwara, Khargoan,	171
Maharashtra	Parbhani, Hingoli, Nagpur, Akola, Wardha, Yavatmal	581
Karnataka	Haveri, Gulbarga, Belgaum, Mysore	201
Tamilnadu	Coimbatore	50
West Bengal	Sundarbans	75

* data from Andhra Pradesh yet to be compiled

Preliminary analysis of the data (zone-wise) indicates that;

- Across the zones, 90% of the total respondents indicated that monsoon is delayed. However, respondents from South zone (Karnataka and Tamil Nadu) did not feel the delay as much as others.
- Across the zones, 86% of the total respondents indicated that monsoon has become more erratic. Further, respondents from North (Punjab and Haryana) and Central (Gujarat, Madhya Pradesh and Maharashtra) zones had a stronger opinion about this fact.
- Across the zones, 77% of the total respondents felt that dry spells were of longer duration. In fact the respondents from North and Central zone had a stronger opinion about this.
- Across the zones, 72% of the total respondents felt that duration of winter decreased. Understandably the respondents from South zone were uncertain about this fact.
- Across the zones, 61% of the total respondents observed increase in crop failure in recent years. The degree of crop failure was severely felt in the Central zone

On their opinion regarding options in wake of delayed onset of monsoon, the repose was as follows:

If monsoon was delayed by 2 weeks

- Majority of the respondents (65%) reported that they would not change any practice (variety, seed rate, crop etc.)

But, if monsoon was delayed by 4 weeks

a) 25% of the respondents would resort to change in variety.

b) 42% of the respondents would resort to change in crop.

c) 12% of the respondents would resort to altering agronomic practices.

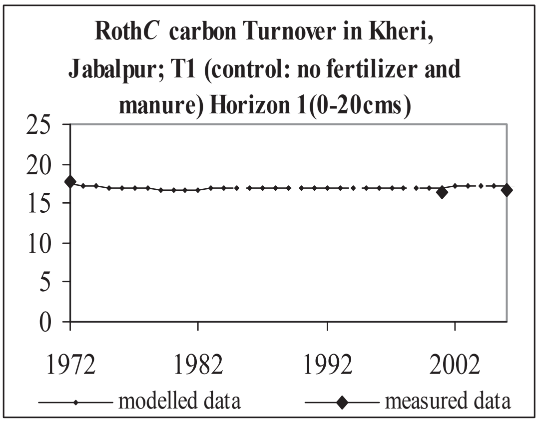
The preferred input management strategy for delayed monsoon in different zones is as follows-

1. Increase fertilizer dose and provide more irrigation – North zone
2. Increase seed rate and reduce fertilizer dose – Central zone
3. Reduce seed rate as well as fertilizer dose – South zone

Objective : To correlate the carbon reserve and its changes with climate change

The LTFT sites for Kheri series Jabalpur (Madhya Pradesh) represent the typical shrink- swell soils of the BSR. LTFT was carried out with a soybean-wheat cropping system in the Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh during 1972-2006. Total five treatments were carried out such as T1: Control (No fertilizers and FYM), T2: 50% NPK; T3: 100%; T4: 100% NPK + HW; T5: 100% NPK + FYM. When T°C was set at the beginning, the model was run for the selected treatments using iteratively selected values for the annual return of plant carbon to the soil.

Jabalpur data showed that organic carbon added through external sources like, FYM (T 5, @15 t ha^{-1}) increases T°C. It was also observed that a regular application of NPK marginally influences T°C during the experimental period (1972-2006) although it registered a T°C increase beyond 2006 when compared with the control (Fig. 122). It seems that the effect of increased dose of NPK with FYM to increase S°C in the tropical climate of BSR is captured by Roth*C* only when the model is run for a considerable period of time.



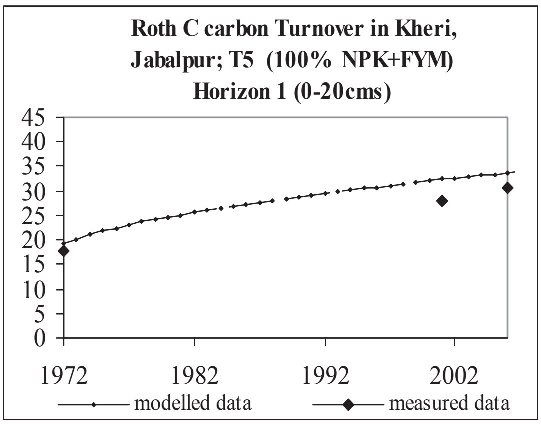


Fig.122. Representing the effect of carbon turnover in control (No fertilizer and manures) and 100% NPK+ FYM treatment

Effect of global warming on modelled T°C stocks

There are efforts to find out relation between global warming *vis-à-vis* modelled T°C stocks, we presumed a subsequent increase in mean annual temperature of 0.25 ^{0}C per decade over 100 years (1990 to 2090) and ran Roth*C*. We used five layers of soil (0-20, 20-40, 40-60, 60-80 and 80-100 cm) and generated datasets for modelled T°C stock. This was compared with the same site T°C stock considering 0-100 cm as a single unit. Roth*C* data (Fig. 123) show marginal difference between modelled T°C stock. T°C held within top 100 cm is found to decrease by 7.85 per cent in single layer when compared to a fall of 7.39 per cent when the same soil was modelled dividing it into five equal layers. The results shows that treating soil as different layers will project actual effects of global warming in accelerating decomposition of soil C and the resultant release of CO_2 from soil organic matter.

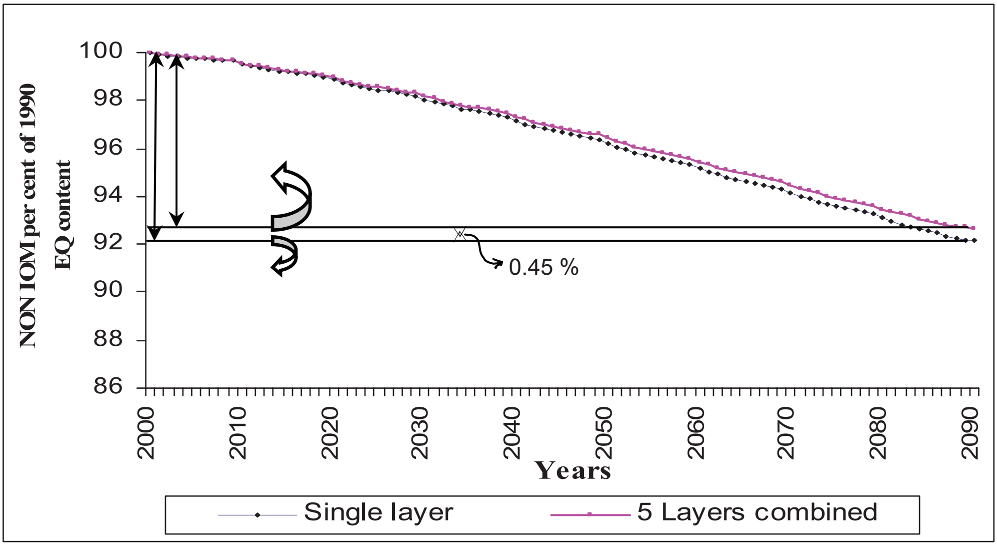


Fig.123. Modelled total organic carbon stocks in Kheri site subjected to an increase of 2.5ºC during 1990 to 2090

The per cent fall in TOC content is more in single layer as compared to combination of 5 different layers. This shows that soil must be considered as an entity of different layers which will mitigate the effect of global warming due to increase in temperature

CENTRAL POTATO RESEARCH INSTITUTE

SHIMLA

Objective: Simulation of impact of climate change on potato in India

Simulation studies with INFOCROP-POTATO model using current and future climate scenarios (A1B) were done for impact analysis of climate change and global warming on potato production in India. Current climate data sets of normal weather for 33 representative sites of concentrated clusters of potato acreage in major potato growing states in India were assembled and used as baseline climate scenario. The down scaled daily weather data from HadCM3 scenarios by the regional climate models (RCMs) of PRECIS either for the baseline or future climate scenarios was not found suitable for simulations accurately, because of several short comings as compared to normal weather data. At many sites potato crop phenology simulated with the extracted data was unrealistic to rely upon for adaptations studies.

Estimation of potato productivity and production: Potato tuber yield was simulated for all the selected sites without adaptations i.e. with recommended date of planting and optimal management practices of seed rate and depth of planting *etc.* for the current and future climates of varying temperature and CO_2 concentrations. Weighted mean potato productivity in different states was extracted from simulated tuber yield of selected locations in each state. Potato production in India at current and future climates was estimated based on relative acreage of different states in total potato acreage in the current base line scenario.

Potato tuber yield

Without adaptations the total potato production in India under the impact of climate change and global warming may decline by 2.61 and 15.32 % in the year 2020 and 2050, respectively (Fig.124).

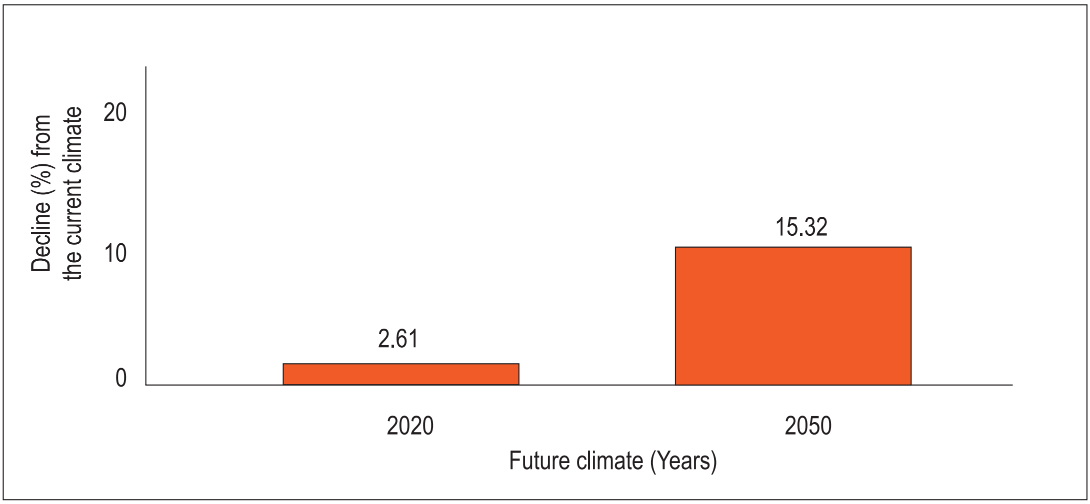


Fig. 124. Impact of climate change on potato production in India

The impacts on productivity and production varied among different agro-ecological zones. Potato productivity is likely to increase in Punjab, Haryana and Western UP by 7.11 and 3.46 % in the year 2020 and 2050, respectively. In other states productivity is likely to decrease by 0.52 to 16.59 % and 0.69 to 46.51 % in the year 2020 and 2050, respectively (Table 58). The mean effect of climate change on potato production in different regions of India is given (Fig.125). Currently the winters are severe in Punjab and Haryana and western UP the north western plains (NWP) witnessing frosting in December and January. In future climate scenarios warming may ease the chilling conditions in these regions to favour potato productivity, while in other regions with relatively milder winters the warming from current levels may prove detrimental.

Table 58. Impact of climate change without adaptations on potato productivity and production in India under current (2000) and A1B future climate change scenarios.

Major States	Mean tuber yield (q/ha)			Production*	
	Years			Change (%) from current	
	2000	2020	2050	2020	2050
UP	210	209	179	-0.52	-14.83
West Bengal	248	237	200	-4.42	-19.45
Bihar	188	184	172	-2.38	-8.62
Jharkhand	145	141	144	-2.51	-0.69
Punjab	211	226	218	+7.11	+3.46
Madhya Pradesh	150	137	124	-8.43	-17.27
Gujarat	226	189	142	-16.59	-37.14
Karnataka	119	97	65	-8.48	-38.92
Maharashtra	100	93	86	-6.58	-13.52
Orissa	129	112	69	-13.47	-46.51
INDIA	183	178	155	-2.61	-15.32

*At constant acreage at current levels

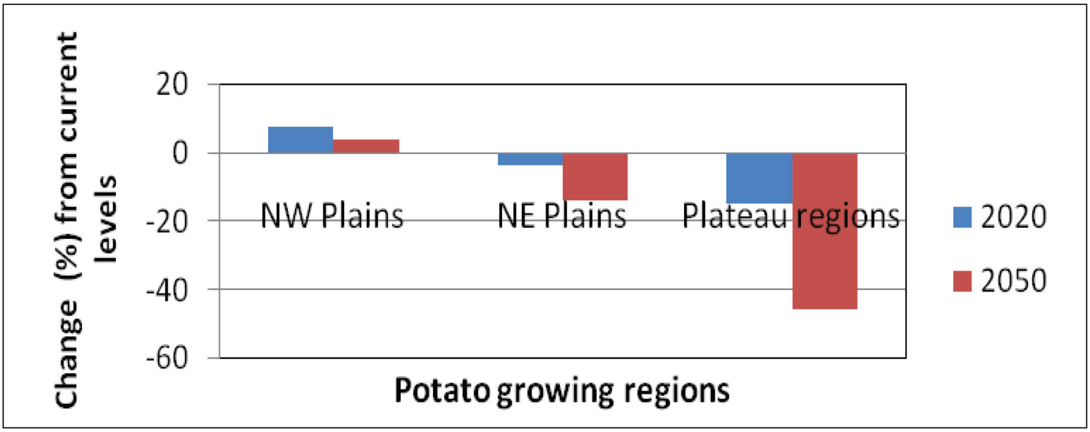


Fig.125. Variable impact of climate change on potato production in different regions of India

Objective : Quantify suitability of agronomic measures in potato for adaptation

Adaptation studies: Simulations were done with simple adaptation measure of change in the date of planting (DOP) to assess its effect on production. The effect of advancing planting (-5 days) and delaying it by (+5 & +10 days) from optimum date of planting (DOP) in the current and future climate scenarios on tuber yield of potato were simulated for the selected sites.

Field experiments: Potato is highly sensitive to untimely erratic rains at the time of planting due to soil crust formation and flooding at all stages of growth to varying degrees. Extreme events are likely to increase under climate change. Therefore field experiments were conducted at Gwalior to assess the impact of flooding and soil crust formation on potato growth and development.

Salient findings

Simple adaptations to climate change

Most inexpensive adaptation option is changing cultivar and date of planting according to the emerging agro-climatic conditions, which can be easily done at the farmers level. In potato the optimum date of planting (DOP) is highly location specific even within small states and varies appreciably according to local weather conditions, soil and cropping systems. Therefore, a general recommendation to advance or delay in future climate scenarios is impractical. However, adaptation studies on change in DOP indicate possibility and extent of sustainable potato production in future climate scenarios by modification in DOP.

Table 59. Effect of adaptation through change of planting date on potato production in few important locations of potato growing areas in India

Indo-Gangetic plains					Plateau region and South India				
Location	DOP	Change (%) in yield			Location	DOP	Change (%) in yield		
		Current	2020	2050			Current	2020	2050
Jalandhar (Punjab)	-5	-5.6	6.7	-3.4	Indore (MP)	-5	-2.0	-8.4	-20.9
	OPT	0.0	7.3	3.7		OPT	0.0	-8.4	-17.3
	+5	15.1	18.1	13.8		+5	-0.2	-4.2	-12.0
	+10	19.4	21.7	18.9		+10	1.4	-14.1	-18.3
Agra (UP)	-5	0.6	-15.2	-36.9	Anand (Gujarat)	-5	-2.6	-21.3	-44.3
	OPT	0.0	-5.6	-7.7		OPT	0.0	-15.2	-47.6
	+5	11.2	1.3	-28.8		+5	-1.4	-18.5	-48.8
	+10	22.1	18.2	14.4		+10	1.2	-5.5	-43.8
Varanasi (UP)	-5	1.9	-0.2	-7.8	Hasan (Karnataka)	-5	4.7	-12.5	-42.0
	OPT	0.0	0.8	-5.5		OPT	0.0	-12.2	-40.9
	+5	-6.6	-4.5	-9.7		+5	-5.0	-16.5	-47.1
	+10	5.1	-3.2	-18.8		+10	-10.5	-19.4	-49.1

Indo-Gangetic plains					Plateau region and South India				
Location	DOP	Change (%) in yield			Location	DOP	Change (%) in yield		
		Current	2020	2050			Current	2020	2050
Patna (Bihar)	-5	-2.8	-11.8	-21.8	Pune (Maharashtra)	-5	-4.9	-20.6	-48.0
	OPT	0.0	-3.1	-10.1		OPT	0.0	-14.4	-47.6
	+5	2.4	-0.3	-2.3		+5	2.2	-7.9	-43.3
	+10	1.2	-1.7	0.7		+10	-1.4	-15.2	-39.9
Burdwan (WB)	-5	-1.4	-7.5	-19.8	Satara (Maharashtra)	-5	-3.9	-7.3	-10.7
	OPT	0.0	-3.9	-7.7		OPT	0.0	-6.6	-13.5
	+5	-8.6	-9.4	-15.5		+5	-3.9	-5.0	-12.5
	+10	-15.0	-19.6	-24.1		+10	-3.4	-10.1	-17.1

DOP-date of planting indicates decrement or increment of days from optimum for the location; OPT-optimum date of planting

In Punjab and Western UP the delayed planting by 5-10 days generally increased or sustained the tuber yield in warmer 2020 and 2050. In these frost prone areas in the current climate the prime concern was to escape the frosting period in late December and early January by selecting an optimum planting date (OPT) allowing at least 75-90 days of growing period. Even in the current climate during frost free years delayed planting was found beneficial but is not recommended due to enhanced risk of frost damage. In Eastern UP and Bihar the delayed DOP by 5 to 10 days might sustain the potato production with only minor losses (0-10%) in tuber yield in future climate scenarios. In West Bengal (WB) there is no advantage from delayed planting and recommended DOP is the best option with a loss of 4-8% only. In WB, other adaptation measures like heat tolerant varieties, mulching *etc.* may prove beneficial. Similar was the situation in plateau and South India with yield losses of 4-49.1% depending upon the location (Table 59). Results indicate that for states of WB, plateau region and south India development of heat tolerant varieties and other adaptation measures need to be developed as change in DOP might not be very effective.

Impact of flooding and soil crust formation: Results of field experiments conducted at Gwalior to assess the impact of flooding and soil crust formation on potato growth and development are inconclusive and are being analysed.

Objective: Compilation of indigenous traditional knowledge to overcome climatic extremes

Indigenous technical knowledge (ITK) of significance to potato crop like predicting winter rains and frost were compiled from different sources. Potato is highly sensitive to frosting and winter rains are associated with dreaded late blight disease epidemics in India. ITK to overcome or minimize the frost damage were also compiled

Predicting winter rains: Ants coming out of their nests and resting places carrying their pupae indicates that rain will come soon within 2-3 days.

Predicting frost: If there is rain on 7th day of next fortnight of the month of shravan, the likelihood of frost that winter is high, while rain on 8th day of next fortnight of the month of shravan (***Janamashtami***) reduces the chances of frost that winter.

ITK to prevent frost damage in potato:

1. Smoking and fumigation by burning cowdung cake, used engine oil and farm waste near fields reduces the frost damage.
2. Smoking by burning farm waste, cowdung cake and old and used tyres in a shallow pit in middle of the field.
3. Growing tall hedges around the field at borders.
4. Dusting wood ash and cowdung cake ash over the crop.
5. Irrigating the field before and during frosting.

NATIONAL RESEARCH CENTRE FOR AGROFORESTRY
JHANSI

Objective: **Compendium of ITK related to agroforestry and climate change in Bundelkhand region**

Questionnaires were prepared related to climate change (rainfall prediction, change in temperature, change in rainfall pattern and other climatic variations and their impact on trees as well as on agriculture) and farmers were interviewed, interacted at village level in different districts of the region. The view of farmers and proverbs related to climate were recorded in the local language and translated into English. The following proverbs are commonly used by the farmers regarding prediction of rain, temperature, crop yield, fruit yield and changes in tree behavior in the region. Some new observations were also recorded related to climate change and their impact on trees.

Achievements

The detail report related to compendium has already been submitted to the Net Work Coordinator. However, some facts/ new observations are given below:

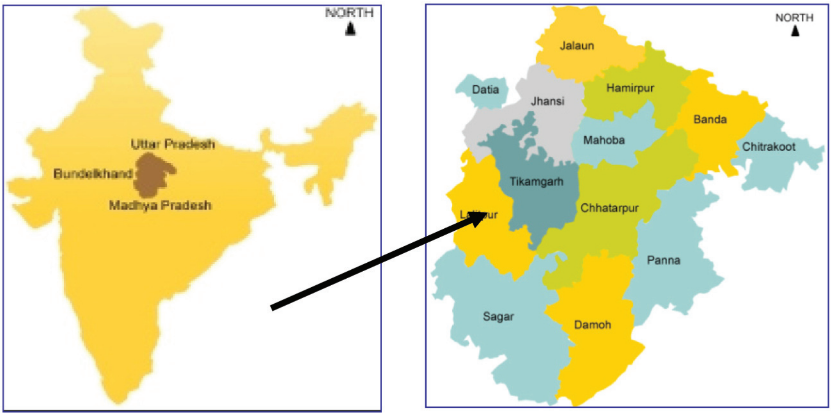
1. When flowering starts in *Saccharum spontaneum,* it means the rain would be terminated.
2. If millipede coming out from soil, it indicates that rainfall is ended.
3. If Pea-cock is shouting it means rain will begin.
4. Cuckoo starts speaking then rain will occur.
5. Monitor lizard stopped speaking then there is end of rain.
6. If new flushes come in the month of June then rain will be begun.
7. Head of chameleon is reddish then rainfall begins.
8. Wind blowing started East side then fruit will have increased sweetness.
9. White ibis are seen on the road and field, it means rain is ended.
10. Black throated weaver (Baya) birds started making the net; it means rain will be terminated.
11. Rainbow seeing in the sky, it means rain will be ended.
12. Net making started by spiders, it means rain will be terminated.
13. Due to climate change few neem trees yielded fruits twice in a year.
14. Flowering was observed in November in few mango trees. Normally flowering starts in January.

Objective: Carbon sequestration potential of agroforestry practices in Bundelkhand region

Development of Baseline

Land use system of different districts of Bundelkhand region

Bundelkhand regions spread over 13 districts out of which 7 districts belong to Uttar Pradesh and 6 districts to Madhya Pradesh. The study was under taken in 7 districts of Uttar Pradesh.



The trees occur either on field bunds or scattered in the fields. All trees are naturally grown and about 41 tree species are found in the farmer's field. These trees belong to slow growing, medium growing and fast growing according to their growth habit. Farmers grow rice, soybean, blackgram, greengram, groundnut, sesame and pigeonpea in *kharif* and in r*abi*, they grow wheat, barley, chickpea, lentil, pea, mustard and taramira. In some districts the farmers grow sugarcane also and in other districts the farmers are also growing blackgram and greengram as *zaid* crop. The details of land use pattern of Bundelkhand have been given in Table 60.

Table 60. Land use pattern of Bundelkhand in ha (U.P.)

District	Reported area	Forests	Wastelands	Non-agriculture lands	Agriculture lands
			(Area in hectare)		
Lalitpur	507500	76160	99346	54000	277994
Hamir pur	390178	23520	26313	39626	300719
Jalaun	454434	25640	29693	48805	350296
Chitrakoot	338897	55754	56808	52485	173850
Banda	438767	5228	41239	40828	351472
Mahoba	327429	15992	27649	45487	238301
Jhansi	501329	34378	52012	73561	341378
Total	2958534	236672	333060	354792	2034010

Source: Directorate of Economics and Statistics, Ministry of Agril. Govt. of India (2004-05)

General information of different districts of the region

The general information about each district (situation, boundary, soil type, rainfall, temperature, and human and livestock population) and maps of each block of all the Districts were collected from District Economics and Statistics Officer (DESTO) from District Head Quarter. The map of each block was used to select the village and their location to conduct the survey of village. The general information about each districts have been given in Tables 61a and b.

Table 61a. General information about different districts of Bundelkhand region

Items	Jhansi	Jalaun	Hamirpur
Geographical area (ha)	507500	454434	390178
Location	25^0 43' N Latitude and 78^0 58' E Longitude	26° 9' N Latitude and 79° 21' E Longitude	25^0 7'N & 26^0 7' N Latitude and 79^0 17'E & 80^0 21'E Longitude
Boundaries	Jalaun, Hamirpur, Mahoba, Tikamgarh, Datia and Lalitpur	Kannpur dehat, Hamirpur and Jhansi	Jalaun (Orai), kanpur Fatehpur, Banda, Mahoba and Jhansi
Climate			
Rainfall* (mm)	625.88	524.83	625.17
Min Tem (^{0}C)	12.93	15.70	12.92
MaxTem (^{0}C)	32.57	34.85	32.60
Rivers	Betwa	Yamuna, Betwa	Yamuna, Betwa Dhasaan, Barma
Population			
Human	17,44,931	17,46,715	10,42,374,
Livestock	7,79,215	7,92,572	5,80,326

* Average of last five years

Table 61b. General information about different districts of Bundelkhand region

Items	Lalitpur	Mahoba	Banda	Chitrakoot
Geographical area (ha)	438767	NA	438767	338897
Location	24°11' to 25°13'N Latitude North and 78° to 79^0 11' E Longitude east.	25^0 18'N Latitude and 79^0 53'E. Longitude	24º 53' and 25º 55' N Latitude and 80º 07' and 81º 34' E Longitude	24^0 48' to 25^0 12' N Latitude and 80^0 58' to 81^0 34' E Longitude
Boundaries	Jhansi, Sagar, Tikamgarh, Chhatarapur, Shivpuri and Guna	Jhansi, Hamirpur, Banda and Chattarpur	Fatehpur Chitrakut Hamirpur Mahoba Satna and Panna	Kaushambi, Satna (M.P.) & Rewa (M.P.), Allahabad and Banda
Climate				
Rainfall*(mm)	746.65	Not available	829.55	Not available
MinTem (^{0}C)	12.40	12.60	12.30	13.20
MaxTem(^{0}C)	32.80	32.21	36.30	32.60
Rivers	Betwa, Dhasan	Betwa, Dhasan	Ken, Baghain and Yamuna.	Madakini
Population				
Human	9,77,447	7,08,831.	15,00,253	8,00,592
Livestock	7,73,511	5,08,468	8,03,746	6,84,939

* Average of last five years
Source: District Economics and Statistics Officer (DESTO), Shankhakiya Patrika, 2006-07

Rainfall of Jhansi district on daily basis for the period of 1944 to 2006 was obtained from Indian Meteorological Department (IMD), Pune and from 2007 to 2009 was recorded at National Research Centre for Agroforestry, Jhansi. Average annual rainfall for the period of last 66 years was 877.4 mm, however during last 9 years it was 729.4 mm, about 17 per cent less than the long term average. Number of rainy days was also declined by 16 per cent during last 9 years. Max. and min. temperature of Jhansi district on daily basis were also obtained from IMD, Pune for the period of 32 years (1975-2006). Analysis at an interval of 10 years revealed that the average min. and max. temperature were flat during the month of November, December and February, however, there was a declining trend in both the cases for the month of January. The rainfall and temperature are not available for other districts.

The carbon pools selected for base line development are aboveground biomass, belowground biomass and soil organic carbon. Dead wood was not included as this was not a major carbon pool under agroforestry.

Above ground biomass

Each district has been divided into number of blocks and each block is having a number of villages. Since it was not possible to cover each and every village, a sample of six villages per block was selected for the field survey in such a way that they truly represent the whole block to which they belong. After the selection of the villages, the field survey was conducted in these villages. The survey was conducted on the basis of transect walk in the village. The village head, local farmers and village youth were associated in the transect walk to have a clear picture of the village. The sampling on farm lands involves enumeration of all trees on farmlands, farm bunds, culturable wastelands etc. All trees more than 1.5 m tall or more than 5 cm dbh were enumerated. The data was obtained for the number of trees for each tree species and the diameter at breast height (dbh) for each tree. In this way, the data was generated for different tree species and their intensity for a particular village. Species specific or generic volume equations from FSI Report (2009) were used to convert dbh into volume cu m per hectare. These tree species were classified as slow, medium and fast growing depending upon their growth habit and MAI. The number of trees per hectare was calculated for slow, medium and fast growing trees per village. This was multiplied with the total number of villages per block and thus calculated for all the blocks of a particular district. The data from all the seven districts was computed and estimation was made for whole of the region. The data was used in CO_2 fix 3.1 model. The component wise biomass was estimated on the basis relative to stem growth. Wood litter was estimated on the basis secondary data and converted into turn over rate of each component. The main parameters used for input datasheet are mentioned below (Table 62).

Table 62. Main parameter used for simulating the uneven-aged trees in agroforestry practices using CO_2 Fix model

Cohorts	Slow growing tree	Medium growing tree	Fast growing tree	Under-storey
Average age of tree (yr)	40	30	15	-
Corresponding DBH (cm)	29	23	12	-
Rotation (year)	61	56	36	0
Corresponding DBH (cm)	44	42	27	-
Wood density (kg m^{-3})	0.67	0.65	0.61	-
Carbon content (% of dry weight)	48	48	48	48
Turnover rate per year (in fraction)				
Foliage	0.6	0.5	0.4	0.9
Branch	0.02	0.01	0.01	-
Roots	0.02	0.02	0.02	0.9
Use of stem, branch and leave (in fraction)				
Stem log wood	0.8	0.8	0.8	-
Stem slash	0.2	0.2	0.2	-
Branch log wood	0.2	0.2	0.2	-
Branch slash	0.8	0.8	0.8	-
Foliage slash	0.3	0.3	0.3	0.80
Foliage slash soil	0.7	0.7	0.7	0.20
Tree	Cellulose (%)	Hemi-cellulose (%)	Lignin (%)	Water soluble Compound (%)
	14.9- 27.5	8.4 - 12.26	11.5-13.8	23.3-32.77
Crop - legume	23.63-29.28	7.06-10.95	9.61-12.27	22.8-32.65
Non - legume	28.36-32.23	19.06-24.83	5.81-8.01	22.6-32.84

Soil Organic Carbon under baseline

The information on soils was collected from assistant director agriculture (soil) of each district during survey. The soils of bundelkhand are broadly classified into two groups viz. red and black. Red soils are divided into Rakar and Parwa type of soils whereas, Black soils into Mar and Kabar soils type. The soil organic carbon varied from 6.7 to 10.3 t C /ha.

Biomass stock under baseline

The biomass stock (above and below ground) in trees was estimated using CO_2 Fix model. The total biomass under baseline varied from 7.48 to 29.95 t/ha in different districts of Bundelkhand region.

Collection of required input data for CO_2 Fix Model on various aspects

The total area of Bundelkhand (Districts of Uttar Pradesh) is 2.958 million hectares. Out of which 8% area is under forests, 11% area under wastelands, 12% area under non-agriculture and 69% area under agriculture. In different districts, 41 tree species were found during survey and tree density varied in different districts (Table 63). The crop productivity during kharif varied from 0.227 to 0.977 t ha^{-1} $year^{-1}$ and in Rabi it varied from 0.64 to 1.74 t ha^{-1} $year^{-1}$. Farmers of Hamirpur, Jalaun, Jhansi, Chitrakoot and Banda are also growing sugarcane and farmer's of Lalitpur, Hamirpur, Jalaun and Jhansi are growing blackgram and greengram during *zaid* crop (summer crop).

Table 63. Tree density in different districts

Districts	No. of trees/ha			Total
	Slow	Medium	Fast	
Jhansi	3.29	7.01	1.27	11.56
Lalitpur	4.79	8.10	3.07	15.95
Hamirpur	2.96	5.12	0.46	8.53
Jalaun	0.73	2.76	0.81	4.31
Banda	1.60	4.25	1.71	7.56
Mahoba	5.72	4.52	1.56	11.80
Chitrakoot	5.64	7.25	1.68	14.57
Mean	3.53	5.57	1.51	10.62

Methodology for estimating carbon sequestration potential of Bundelkhand region Parameterization of CO_2FIX model for District wise survey data of Bundelkhand

CO_2FIX model requires primary as well as secondary data on tree and crop components (cohorts) for preparing the account of carbon sequestered under agroforestry systems on per hectare basis. The primary data includes the name of the tree species on farmlands along with their number, DBH (diameter at breast height), crops grown by farmers on farmlands along with their productivity, area coverage etc. Whereas the secondary data includes the growth rates of tree biomass components (stem, branch, foliage and root) for various species on annual basis as well as the productivity of different crops grown in that region.

Tree growth equations, available in FSI-2009 report for the species found in survey, were used to generate the DBH (m) and stem volume (m^3/tree) data. The individual species wise generated data sets were then clubbed into single files for the slow, medium and fast growing species separately. These three data sets pertaining slow, medium and fast growing species were independently used to fit non-linear functions for stem volume-DBH relationships. These tree wise absolute stem volume-DBH relationships were then converted into hectare wise stem volume-DBH relationships, by multiplying tree wise stem volume from the average number of trees found in a village in a specified category (slow/medium/fast). This DBH was transformed back into age to obtain hectare wise stem volume –age relationships. Ultimately, these absolute stem volume values were converted into CAI (current annual increment) values of stem volume by taking the difference of current year value from preceding year value. Thus, we obtained the CAI equations for stem-volume-age for the three categories/cohorts of slow, medium and fast growing trees in a given district.

The harvested data available for different tree species (classified under the slow, medium and fast growing categories/cohorts) at National Research Centre for Agroforestry, Jhansi was used to find out the relative growth of foliage, branch and root with respect to stem. These relative proportions were parameterized in CO_2FIX model for branch, foliage and root growth.

In order to simulate the crop component, the crop was considered as a ‘tree’ with a very small stem volume, no branches and a lot of foliage and roots. The aboveground production crop component is 2546*0.09*0.01 = 2.29 tons DM ha^{-1}. Similarly, belowground production is 0.74 Mg DM ha^{-1}. Characteristic for cropland systems are the high turnover rates in foliage and roots, in this case set at 0.9 for both. Main parameter used for simulating the uneven-aged trees in agroforestry practices using CO_2 Fix model have been given in Table 64.

Table 64. Tree and crop biomass (above and belowground), soil carbon and carbon sequestered in different districts of the region

Year	Tree biomass	Crop biomass	Soil Carbon	Carbon sequestered
	(Tonnes per hectare)			
2010	22.36	5.77	9.21	22.42
2015	22.88	6.01	14.85	29.50
2020	27.65	5.78	15.80	31.54
2025	30.47	5.61	16.68	33.72
2030	33.15	5.50	17.38	35.78

Salient findings

Simulation of tree and crop biomass (above and belowground), soil carbon and carbon sequestered was done for 21-years in each district on per hectare and average values of all the districts have been presented in Table 64. The values of above parameters were converted on regional basis by multiplying the area under agriculture in which trees are growing naturally or planted by the farmers. On an average tree biomass in 2010 was 22.36 t ha^{-1} and after 21-years it would be 33.15 t ha^{-1}in different districts of Bundelkhand region. Similarly, soil carbon in beginning was 9.21 t C ha^{-1} and in end of rotation period the soil carbon would be 17.38 t C ha^{-1}. The crop biomass was higher in beginning and it was reduced in subsequent year. Carbon sequestration potential varied in each districts and it depends upon the tree density, growth and age of trees. On an average carbon sequestered in different districts of the region during 2010 was 22.42 t C ha^{-1} and likely to increased up to 35.78 t C ha^{-1} at end of the rotation period. The tree biomass, soil carbon and carbon sequestration potential of region in 2030 would be 67.42, 35.36 and 72.77 million tones (Table 65).

Table 65. Biomass and carbon sequestration potential of the region

Year	Tree biomass	Crop biomass	Soil Carbon	Carbon sequestered
	(Million tones)			
2010	45.48	11.73	18.73	45.61
2015	46.53	12.23	30.21	60.01
2020	56.25	11.76	32.13	64.16
2025	61.98	11.40	33.93	68.59
2030	67.42	11.18	35.36	72.77

Cost benefit of agroforestry practices in Bundelkhand region

The expenditure on labour and mechanical power for different operations such as land preparation, sowing, harvesting, threshing etc. was calculated at the prevailing market prices for 21-years period. The cost of other inputs such as crop seed, tree sampling, fertilizers, insecticides, management cost of tree etc. was calculated based on actual requirement per hectare basis. The income was calculated on the basis of productivity of different crop in each district. The straw yield was calculated on the basis of grain: straw ratio given in published literature. The income from tree was calculated for pruned biomass every year as fuel wood and finally wood obtained from final harvest. The income from stem log, stem slash, branch log and branch slash was calculated on the basis of assumed market price of each harvested component.

The discounted cost at 15% discount rate varied from Rs. 175959 to 196837 per hectare in different districts of Bundelkhand region in period of 21-years. Similarly discounted benefit varied from Rs 309732 to 312922 per hectare in different districts in period of 21-years. The benefit: cost ratio of agroforestry practices varied from 1.38 to 1.94 in different districts.

Organizing farmers' fare/Kishan Gosthi to sensitize farmers about climate change

The Centre has organized Kishan mela/ Kishan Gosthi and also celebrated world environment day and earth day. The expert scientists has given idea on present situation of rainfall pattern, temperature to the farmers so that farmers know about the changing pattern in rainfall and make a strategy for crop cultivation and tree plantation accordingly.

CENTRAL SOIL SALINITY RESEARCH INSTITUTE
LUCKNOW

Objective : Climate scenario of Indo-Gangetic belt (Lucknow, Kanpur and Faizabad)

Salient findings:

Temperature

Annual maximum and minimum temperature:

Average annual maximum and minimum temperature (Fig. 126 & 127) were found affected with the due course of time. The rise in maximum and minimum temperature was ranged from 0.15 to 1.22°C and 0.003 to 0.67°C respectively, for all the stations for the period of 2005-09 over the temperature of 1980-84.

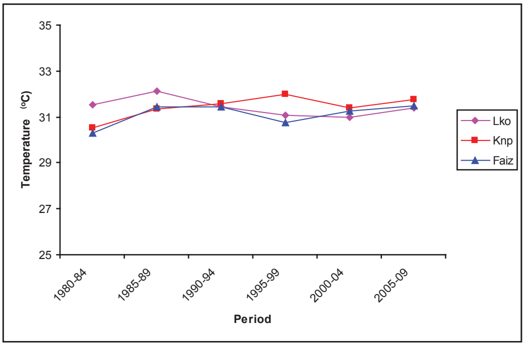


Fig.126. Five years average maximum temperature (°C) of Lucknow, Kanpur and Faizabad

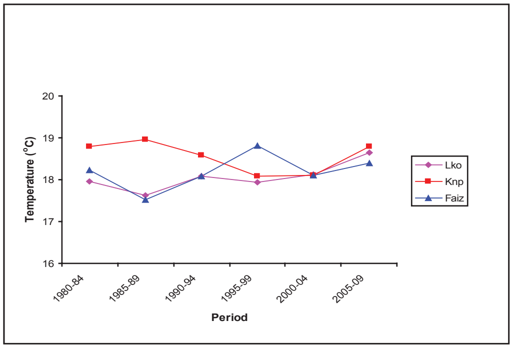


Fig.127. Five years average minimum temperature (°C) of Lucknow, Kanpur and Faizabad

Maximum and minimum temperature of March and May

On comparison of month wise temperature data, it was found that temperature of March and May months of recent years were more affected when compared with the past years. Average maximum and minimum temperature in March (Fig. 128 & 129) for the period of 2005-09 was recorded as 0.16°C & 0.88°C, 2.04°C & 0.95°C and 0.69°C & 0.35°C higher for Lucknow, Kanpur and Faizabad stations respectively when compared with the temperature for the period of 1980-84.

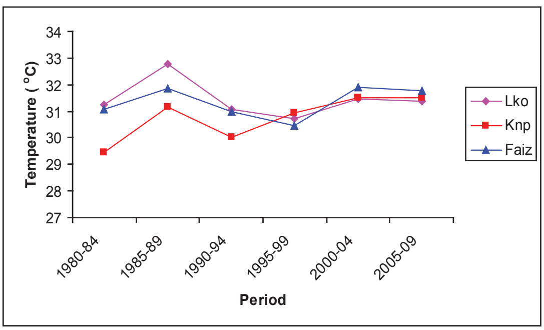


Fig.128. Five years average maximum temperature (°C) of March

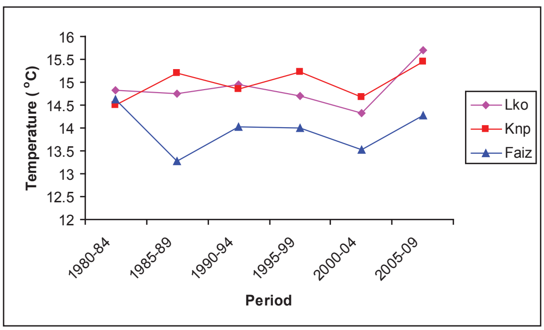


Fig.129. Five years average minimum temperature (°C) of March

The same when compared for the month of May (Fig. 130 & 131) was found showing reverse trend. Maximum and minimum temperature was recorded 1.58°C & 0.23°C, 0.49°C & 0.59°C and 0.70°C &1.36°C lower against the temperature for the period of 1980-84 for Lucknow, Kanpur and Faizabad, respectively.

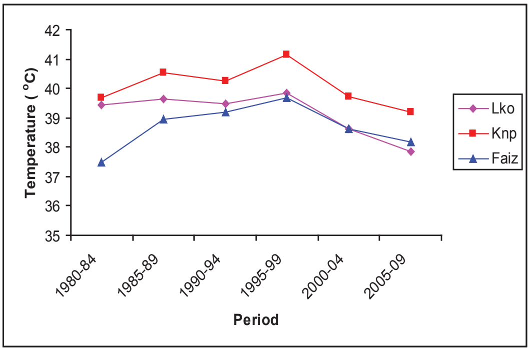


Fig.130. Five years average maximum temperature (°C) of May

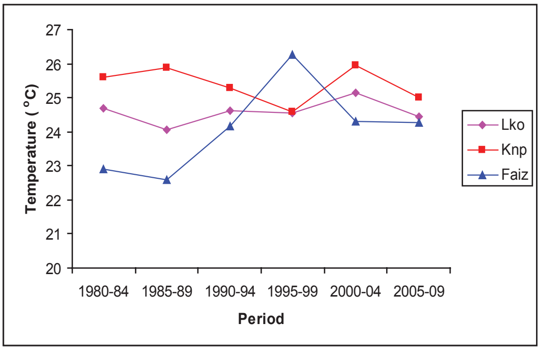


Fig.131. Five years average minimum temperature (°C) of May

Rainfall pattern:

At Lucknow highest average 1180.99 mm rain was recorded for the period of 1980-84 with the average 64 rainy days where as the same was reduced to 884.38 mm with average of 71 rainy days for the period of 1995-99. The period of 2005-09 it was recorded 17.47% lesser rain than the period of 1980-84.

At Kanpur average of total rain and total number of rainy days were found to follow a decreasing trend. Average rainfall of 1197.76 mm was recorded with the average of 68 rainy days for the period of 1980-84, where as 36.06% less rain (765.88 mm) was recorded having average of 58 rainy days for the period of 2005-09.

At Faizabad station the highest average rain were found 1256.97 mm with the average of 72 rainy days. The lowest rain of (842.16 mm) was recorded for the period of 1990-94 with the average of 56 numbers of rainy days whereas for the period of 2005-09 it was recorded 984.32 mm with 61 rainy days which was 21.69% less rain over the period of 1980-84.

Objective : Impact of climate change on wheat yield under sodic soil condition in Central Uttar Pradesh

Salient findings: It was observed that the maximum and minimum yield was recorded during the period of 2007 and 2010 against the average mean temp of 21.82°C and 25.65°C of March, respectively (Table.66).

It was also noticed that the yield of wheat in 2010 was 28% lower over the previous year which might have been due to the shrinkage of wheat grain resulted from higher temperature during the month of March in spite of prolonged winter during December to February. The data are also used for establishment of the relationship between the temperature and yield of the wheat (Fig.132).

Table.66. Average temperature of March and wheat yield for corresponding years

Year	Average Temperature (°C)	Yield of wheat (qha^{-1})
2003	22.53	14.95
2004	24.54	16.47
2005	24.68	16.23
2006	23.37	14.77
2007	21.82	22.64
2008	24.28	18.27
2009	23.54	19.32
2010	25.65	13.91

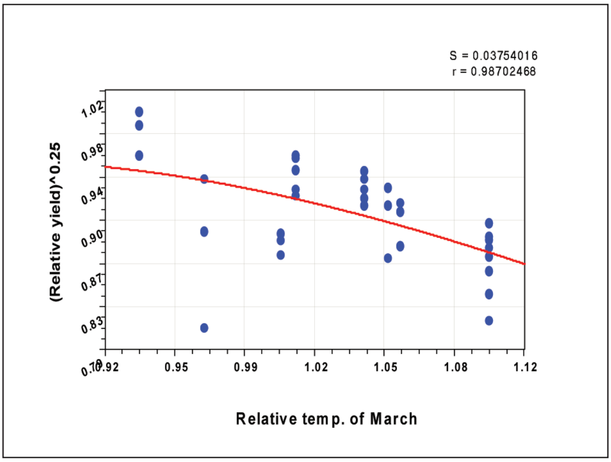


Fig.132. Heat capacity model of temperature vs wheat yield

The response curve was tested using heat capacity model for the yield of wheat in relation to temperature pattern (y=a+bx+c/x^2; where, a =2.4968034, b=- 1811258 & c =-0.3880648). Analysis of curve showed that about 8% wheat yield will be decreased with 1°C rise in temperature over the standard temperature of 23.3°C of March.

Objective : Study the carbon sequestration potential of different Land use systems

Methodology: Soil samples were collected from the different land use systems established at CSSRI-RRS's research farm Shivari, Lucknow**.** Five important land use and soil management system chosen for the current investigation comprised of two agro-forestry tress species *viz. Prosopis juliflora* L. (AFP) and *Casuarina equisetifolia* L. (AFC), two horticultural tree species *viz. Tamarindus indica* L. (HI) and *Syzygium ciminii* L. (HJ) and rice-wheat cropping system treated with gypsum (RW). These systems were analyzed for their carbon sequesters potential. Soil organic carbon including particulate organic carbon and microbial biomass carbon were analysed at different depth for different systems.

Table.67. Carbon sequestration rate (Mg ha^{-1} year^{-1}) after 10years of land use and soil management systems

LU & SMS	Sequestration potential		
	SOC	POC	MBC
AFC	0.703	0.101	0.018
AFP	0.826	0.071	0.023
HJ	0.515	0.043	0.013
HI	0.455	0.067	0.013
RW	0.689	0.043	0.017
LSD(p=0.05)	0.152	0.018	0.005

LSD-Least significant difference at p=0.05. LU=Land use, SMS=soil management system, SOC=Soil organic carbon, POC=particulate organic carbon, MBC= microbial biomass carbon

Salient findings: Significant differences in SOC and their fractions in sodic soil under different land-use and soil management system indicated that soil carbon can be sequestered by reclaiming the sodic soil either through biological means of planting tolerant species or through chemical amendment by gypsum application (Table.67). Agro-forestry plantations accumulated more particulate organic carbon (0.071 to 0.101 Mg ha^{-1} year^{-1}) i.e. a physically protected moderately labile pool than other systems (0.043 to 0.067 Mg ha^{-1} year^{-1}). Agro-forestry system protected the P°Cwell due to non disturbance of soil in the system. The effect of soil depth on microbial biomass carbon was significant under agro-forestry and horticultural plantations reflecting steep decline in MBC in subsurface layer. Dispersion of aggregates containing organic material, caused by sodicity, also increases the availability of C, resulting in an increase in its accessibility and degradability for the microbial population. A positive build up of different organic carbon fractions in agro-forestry and horticultural systems takes place mainly due to long term addition of C through leaf litters and rhizodeposition which in turn facilitate the reclamation process in sodic soil.

Calibration and validation of Rothamsted Carbon model is under progress for different land use systems.

Objective : Calibration and validation of InfoCrop model under sodic environment

Methodology: Site was selected at CSSRI-RRS research farm, Shivari, (80.9 longitudes, 26.5 latitude and 110 altitudes). The soil pH ranged from 9.0-9.5, EC 0.2-1.5 dSm^{-1}, and organic carbon ranged from 2.0-3.0g kg^{-1}. The required data of crop phenology, meteorological data (Temperature maximum and minimum, solar radiation and precipitation etc.) and soil data were collected from various sources.

Salient findings: InfoCrop model is calibrated and validated for two salt tolerant rice varieties for selected location. The model has been calibrated first for rice varieties viz. CSR 13 and CSR 23 for the year of 2001 and 2006, respectively and this calibrated model is validated for successive years. Yield data of both rice varieties for different years were collected. The input data for simulation of model is predetermined and fixed. These data were changed to the required format of model.

The grain yield of crop that was simulated by InfoCrop model was compared with the observed yield and per cent of deviation was calculated. For CSR 13 predicted grain yields in all the treatments were in good agreement with the observed yields having RMSE=0.421 (Table 68). For CSR 23, model is calibrated and validated for two sowing methods; transplanted and direct seeded (RMSE=0.264 & 0.529) and results were found harmonically as par with the observed yield (Table: 69 & 70). RMSE values were calculated as RMSE = $\sqrt{\sum (Y_i^{obs} - Y_i^{sim})^2}$.

Table 68. Observed and simulated yield of rice var. CSR 13 under transplanted condition at Shivari, Lucknow

Year	Observed Value (t ha^{-1})	Simulated Value (t ha^{-1})	% Deviation
2001	4.6	5.1	-10.9
2002	4.8	4.9	-2.1
2003	4.9	4.3	12.2
2004	4.8	4.5	6.3
RMSE		0.421	

Table 69. Observed and simulated yield of rice var. CSR 23 under transplanted condition at Shivari, Lucknow

Year	Observed Value (t ha^{-1})	Simulated Value (t ha^{-1})	% Deviation
2006	4.8	5.1	-6.3
2007	4.3	3.9	9.3
2008	4.1	4.0	2.4
2009	3.4	3.5	-2.9
RMSE		0.264	

Table 70. Observed and simulated yield of rice var. CSR 23 under direct seeded condition at Shivari, Lucknow

Year	Observed Value (t ha^{-1})	Simulated Value (t ha^{-1})	% Deviation
2006	4.8	4.4	8.3
2007	4.5	4.4	2.2
2008	4.4	4.7	-6.8
2009	3.4	4.0	-17.6
RMSE		0.529	

Limitation of the model under sodic condition: Under sodic condition the soil pH and EC are important soil factors that directly or indirectly affect the rice yield. In InfoCrop model EC is not functional. The soil pH also does not show any significant effect on rice yield whereas under field condition it is observed that the rice yield drastically get reduced when pH goes above 9.4 under sodic conditions.

The calibration and validation of InfoCrop model under sodic soil conditions for different wheat varieties is under progress.

ICAR RESEARCH COMPLEX FOR NEH REGION

BARAPANI

Objective : Collection and documentation of ITKs relevant to climatic variability and agriculture in NEH region

Salient findings:

More than 75 ITKs were collected. Some of the important ones are presented below which have a direct relevance to agriculture.

- The Khasi tribes of Meghalaya have a very unique method of calculating time, adopting the lunar month (*bnai*). The different months and their meaning are generally related to agricultural operations, which, in turn, depend on the general weather conditions:

➢ Rymphang (February) means the "**windy**" month.

➢ Iaiong (April) means the "**changeable weather**" month.

➢ Jylliew (June) means the "**deep water**" month.

➢ Naitung (July) means the "**foul smelling**" month when vegetation rots due to excessive moisture.

➢ Nailar (August) means when the weather clears and the jainailar plant blooms.

➢ Nailur (September) means weeding begins.

➢ Risaw (October) means when autumn begins and the country (ri) becomes red (saw).

➢ Nohprah (December) means when the baskets (prah) for carrying field produce are put away (buh noh), signifying the end of a cropping season.

- If the tadpoles are present in the water surface, there is lesser likelihood of rain, but if the tadpoles are beneath the surface, then rain is likely to occur.
- At the time of harvest of rice, if the rice plants lodge easily, or the grains shatter easily, there is high probability of hail occurring.
- Bleating of goats and moving towards their shed is a sign of heavy rain.
- If the new moon appears directly overhead, drought is expected but if it is not overhead, rain may occur.
- Bringing betel nut from other areas to Ri Bhoi areas of Meghalaya is prohibited until and unless rice is harvested otherwise it will lead to the occurrence of hailstorms.
- If the shoots and buds of the pine trees (*Pinus kesiya*) are curved, there is high probability of rainfall, but if they are straight, the chances of rain are very less.
- During summer, if the Coccinelid beetles sit on top of the rocks, the weather will be rain free. If the insects sit under the rocks, heavy rain is expected.
- In years when there is heavy flowering of jackfruit trees, heavier rain and frequent occurrence of hail is expected.

- If there is ash colour cloud in the north-west to south-eastern side of the sky, there is possibility of rain.
- If dragonfly flies in group, there may be rain sooner than later.
- If red ants move in groups by carrying eggs in their mouth, there is indication of rain.
- If it rains during mid Jan-mid February (shaka month *Magha*), rice can come up well even in uplands.
- Heavy pouring coupled with tremor during mid-August to September (Shaka month *Bhadra*), leads to crop failure and no grain would be available even in the market.
- Rain during mid February –March (*Falguna*); leads to many fold (4 times) bearing in arecanut.

Objective: Detail scenario of climate change in North East India

Salient findings:

The North Eastern Region (NER) of India, by virtue of receipt of heavy rainfall, falls in low rainfall variability category and it ranges from 8-15%. For the North Eastern states of India, the normal annual rainfall ranges from 200-300 cm. Green vegetation, big water bodies and the nature's beauties and mega-biodiversity are the attraction of the NER. But of late, the region is loosing its nature's gifted fame. In high rainfall areas distribution of rainfall is of more concern as compared to its amount received. Erratic nature of rainfall, its intensity and frequency often makes crop planning a difficult task in rainfed areas. The world highest rainfall area Mawsynram / Cherrapunjee also falls within the region. But even so, under the influence of global climate change, high rainfall areas are facing drought like situations in the current years. Unprecedented drought-like situation adversely affected the whole NER in general and Assam in particular during 2006. According to IMD records, the amount of rainfall received by the NER in 2006 monsoon season stands to be the scantiest for a period of 25 years, since 1982. Out of seven NE states, Assam seems to have suffered most from this deficit rainfall and high temperature prevailed in 2006 monsoon season.

Worst was in the year 2009, where, most of the NE states were affected by drought like situations. Manipur, Nagaland, Meghalaya witnessed severe meteorological drought. Other states have recorded moderate drought. Till July, 20, 2009 Manipur recorded 67 % rainfall deficiency followed by Nagaland (-63), Meghalaya (-56), Assam (-34), Mizoram (-32), Tripura (-31) and Arunachal Pradesh (-29). Assam - Meghalaya Division has recorded a deficit of 45% this year compared to 32 % in 1986 making it highest rainfall deficit year in last three decades (Times of India, 22 July, 2009). Arunachal Pradesh (6 districts), Assam (3 districts), Nagaland and Sikkim (1 district in each) remained very severely affected by Drought, which has received less than 55 mm of rainfall in consecutive 4 previous weeks (NESAC, 2009). This has severely affected the transplanting and sowing of rice in the drought affected areas. Between 1991 and 2000, only four years saw normal or above normal rainfall in NER. Consequently, it becomes difficult to complete agricultural operations due to heavy and continuous showers. Coupled with this, the scorching heat further aggravates the situation. One can see crack (small to medium size) in low lands, dried crops in uplands even in the wettest month of July in the region.

The weather this time would have a disastrous impact on the agriculture sector of the State. The dry spell has left a significant number of the farmland in NER without any tilling activities even upto the first week of August. Due to absence of operational irrigation facilities, the farmers faced a totally disastrous condition due to lack of adequate rainfall for paddy cultivation that otherwise face perennial problem of flood during the monsoon season. Estimate of crop (Rice) production loss in Assam has been fixed around 15-20%. This weather condition has also posed a serious threat to the tea and fish sectors. The situation would lead to early closure of the plucking season this time. Crop failure due to a severe drought in previous years left many families penniless and the situation was not likely to improve this year too owing to a delayed and weak monsoon.Drought conditions prevailing in almost all the fish farming areas have adversely affected rearing of fish. The issue attracting a lot of concern is the condition of available fish seed and the prospect of their survival. 'Carried over seed' is the source for farmers to rear the next season's fish. Low water levels in *beels* (natural landlocked water bodies), ponds and rivers, accompanied by high temperature inhibits fish breeding, a phenomenon more pronounced in shallow water bodies. *Son beel* (Karimganj, Assam) case may be referred here for current drought situation. Soaring temperatures lowered the biological oxygen demand (BOD) in ponds, *beels* and man made tanks, which hampered the growth of fish. Reduced fish population in the *beels* located in forests could have an impact on the migratory bird population that flocks to the protected areas every winter. The pine, the naturally dominated tree species in mid-altitudes are encroached upon by another tree species *Schima walchii,* climatic consequences of which needs to be thoroughly evaluated.

Objective : Soil analysis for C balance from agro-ecological zones of Meghalaya

Physico-chemical and biological analysis: Available Nitrogen (N) in soil was determined by Alkaline Potassium Permanganate Method (Subbiah and Asija, 1956). DHA (dehydrogenase activity of soil) was determined by Assay method (Casida et al., 1964)

Soil sample collection at various depths in 5km X 5km grid from different land uses including targeted crops (Rice, Maize, Ginger, Colocasia, Turmeric, Mustard and Orange + Pineapple).The sites for soil sampling and analysis were selected from on-going field experiments of ICAR Research Complex, Umiam, Meghalaya on resource conserving technology such as:

- Conservation tillage
- Organic farming
- In-*situ* residue management
- Long term farming system site

Soil samples were also collected from traditional land use patterns areas like:

- Shifting cultivation (control)
- Pine forest (Botanical Survey of India)

Salient findings:

Physico-chemical properties of soil

Available Nitrogen: Available nitrogen content was recorded maximum in organically managed plot (NOC organic) both at surface and subsurface layers. Maize under conventional tillage (MZ CT) and rice (Rice CT) under conventional tillage systems recorded lowest amount of available N content at surface and subsurface layers, respectively. Higher available nitrogen in organically managed plot (N°Corganic) could be because of the use of chemical fertilizer along with organic manures which supplies readily available forms of nutrients such as nitrogen.

Biological properties of soil

DHA: Dehydrogenase activity MZ ZT (maize under zero tillage) recorded maximum in both the layers whereas Rice CT (rice under conventional tillage) recorded the lowest in both the layers. Dehydrogenase activity of soil is better in MZ ZT (maize under zero tillage) because of better environmental condition for growth and proliferation of microbes brought about by the adoption of conservation tillage along with residue management. However, MZ ZT maize under zero tillage) is better than Rice CT (rice under conventional tillage) because of the difference in the land conditions.

Objective: Trend analysis of weather data and land use change in Meghalaya

Collection and analysis of climate/ land use data

The climate data of Meghalaya varies with topography and prevailing weather conditions. The climate of Meghalaya is mostly influenced by the South west monsoon. Climate data of Meghalaya were collected from India Meteorological department (IMD), Shillong centre and ICAR Research Complex (Observatory), Umiam, Meghalaya. These data included all weather parameters such as rainfall, relative humidity, evaporation, sunshine and temperature. The data collected were based from the collection and observation of the above two centers for a period of 25-27 years i.e. 1983 to till date. Trend analysis of the meteorological data were done taking the monthly trend, seasonal and annual trend and to check its impact on agriculture.

Salient findings:

Sunshine Hour: The duration of sunshine is one of the weather parameter which helps in the field of agriculture especially in the process of photosynthesis were plants take full advantage of the solar radiation. The monthly trend of the duration of sunshine over 22 years (1987- Sept 2009) varies from 2.8 to 7.3 (hrs/day). The maximum sunshine was observed in the month of March at 7.3 (hrs/day) and lowest in the month of July at 2.8 (hrs/day). However, in the month of September to December there was an increase in the duration of sunshine from 3 to 6 (hrs/day). The sunshine hour values remains minimum during the period of June to September (Fig 133).

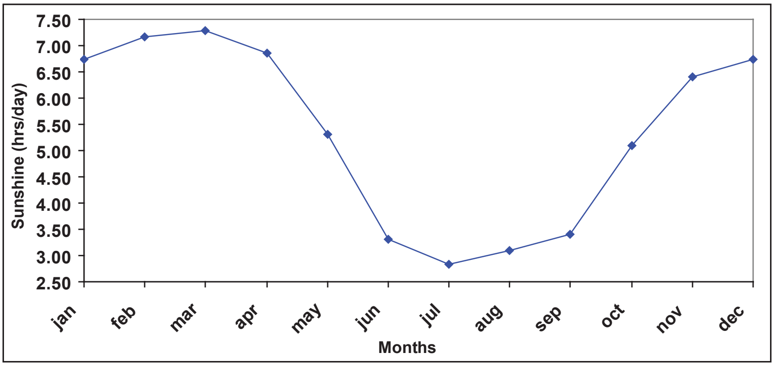


Fig 133. Monthly trends of mean daily sunshine (hrs) over 22 years (1987-2009) at Umiam

Relative humidity: Relative humidity is another parameter of climate which determines the amount of moisture content available for the crop as well as for the soil. The maximum relative humidity (recorded at 08.30 hrs) over 24 years (1985-2009) varies from 65% to 90% and the minimum relative humidity (recorded at 13.22hrs) over 24 years (1985-2009) varies from 50% to 85%. The monthly trend of maximum relative humidity was recorded highest in the month of July and August of more than 85% and lowest in the month of March with 68%. The monthly trend of minimum relative humidity was recorded highest during the period of June to September 80-81% and lowest in the month of March with 56%. This shows that there was a period of period of wet spell in the pre monsoon period and a period of wet spell in the post monsoon period in both the cases (Fig 134).

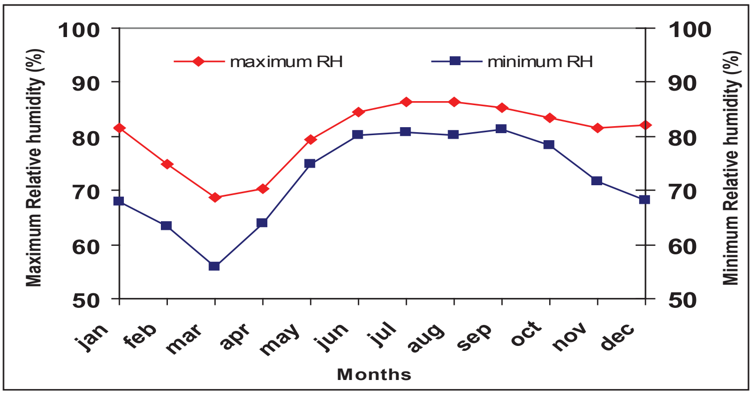


Fig. 134. Monthly trends of mean maximum & minimum relative humidity (%) over 24 years (1985-2009) at Umiam

Air temperature: For successful growing season the knowledge of maximum and minimum temperature is very much essential. The monthly mean maximum temperature varies between 19 ^{0}C and 28^{0}C and the mean minimum temperature varies between 6^{0}C and 21^{0}C. The highest mean maximum temperature was recorded in the month of August at 28^{0}C and lowest in the month of January at 19.3^{0}C and the mean minimum temperature was recorded highest in the month of August at 6.7^{0}C and lowest in the month of January at 20.9°C. This shows that there was a declining trend of temperature received in the winter months whereas the months from April to September show the warmest months (Fig 135).

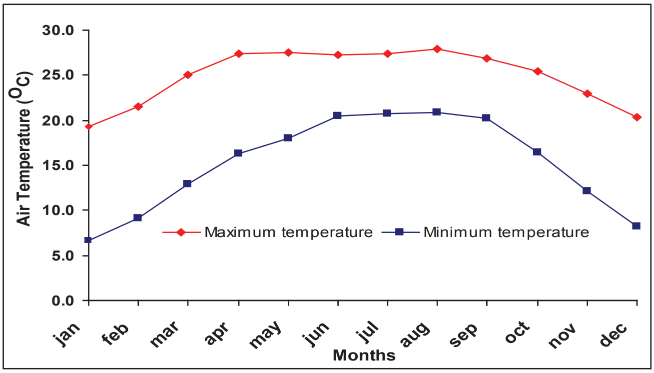


Fig 135. Monthly trend of air temperature over 24 years (1985-2009) at Umiam

Water and climate trend analysis: The water flux of 26 years (1983-2009) at Umiam showed that there was maximum rainfall in the month of July and lowest in the month of January. Evaporation takes place maximum in the month of April and lowest in the month of January. This shows that there was a period of drought in the pre monsoon period and a period of wet spell in the monsoon and post monsoon period. Water deficit occurs in the pre monsoon period. The average of 26 years of climatic water balance also reflects that except in the month of January (-70mm) there is a surplus of water (> 500 mm) during the entire years (Fig 136).

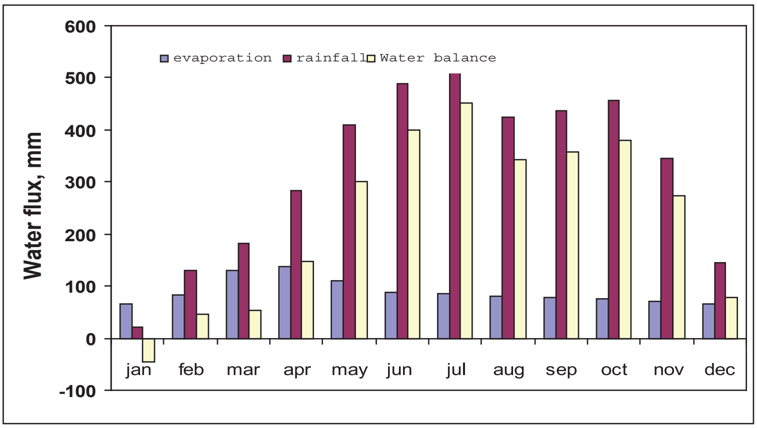


Fig 136. Climatic water flux for 26 years (1983-2009) at Umiam

Land use change

Land use change such as change in forest cover of Meghalaya from 1987-2005 after 2 years interval is analyzed from the data collected from Forest Survey of India (Table 71).

Table 71: Percent annual change in forest cover between 1987 and 2005 in Meghalaya

1987-1989	1989-1991	1991-1993	1993-1995	1995-1997	1997-1999	1999-2001	2001-2003	2003-2005
-2.62	0.72	-0.34	-0.18	-0.18	-0.08	-0.16	3.96	0.19

Source: Forest Survey of India

Salient findings:

Change in forest cover arises as a result of deforestation and clearing huge area of land for agriculture, industries and human settlements. This huge devastation leads to global warming and changing the climate of the area. Fig 137 shows that there was a huge decline in forest cover over a decade (1991-2001).

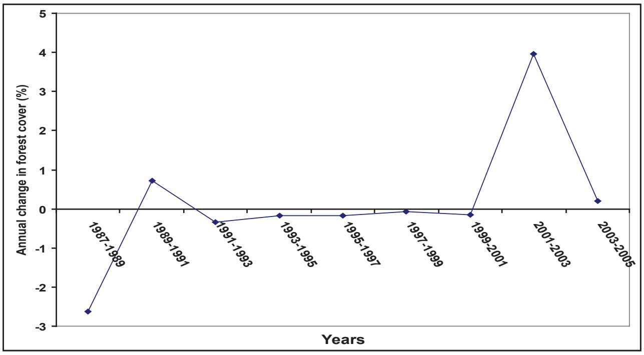


Fig 137. Percentage annual change in forest cover between 1987 and 2005 in Meghalaya

Objective : To estimate C-sequestration & GHG mitigation potential & cost in NEH region Training on C-sequestration model

Training on Roth C and Century models was obtained by Dr. B. U. Choudhury (Co-PI) and Mr. Enboklang Kharkrang (SRF) in the workshop held at NBSS&LUP, Nagpur, from the 19^{th} - 21^{st} Jan, 2010.

Salient findings:

Calibration of the models is in progress, which is delayed by the difficulty to obtain reliable soil data and also because of the heterogeneity of the region.

Data generation on Soil Organic Carbon (SOC) at 2 depths (0-20 and 20-40 cm) or as per the instructions from NBSSLUP during that C model

Soil organic carbon (SOC in %) content was estimated by using Walkley and Black's method (Jackson, 1973).

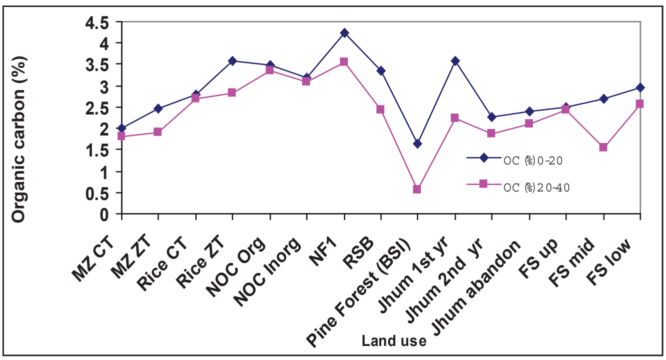


Fig.138. Soil organic carbon as influenced by different land use systems

Salient findings:

SOC recorded maximum in NF1 (in-situ fertility management plot) and minimum in pine forest. Pine forest being undisturbed ecosystem, the rate of decomposition of organic matter is very slow. As a result, less organic carbon is released to the atmosphere (Fig 138).

Objective : Adaptation strategies

For conservation of natural resources and to cope up with the climate change/drought like situations various long term field experiments are conducted in the institute. The results of those experiments were taken to explore the adaptive strategies against climate change. Some of the experiments are:

(1) Variety: In two conditions (a) aerobic and (b) flooded condition

(2) System of rice intensification (SRI).

(3) Adjustment in date of sowing Rice (same variety: 3 dates of sowing)

(4) Conservation agriculture (Zero and minimum tillage, residue management etc.)

Salient findings:

- The field experiments carried out over last 5 years indicated that practices like zero tillage & crop residue management reduces the risk of crop failure especially during dry season. It is possible to obtain a fairly good crop of toria with above practices even in condition of drought.
- Varieties like Sahsarang1 have the more adaptability to occasional draught and gives fairly good yield in condition of drought like situation.
- Transplanting during first week of July to mid July is found to be the good timings in mid hills of Meghalaya for rice. In case of delay in transplants, verities like V. Dhan 82 performed well.
- System of Rice Intensification (SRI) method reduced the rice duration by 15 days and require less water and so suitable for less water availability condition.

PROJECT DIRECTORATE ON POULTRY
HYDERABAD

Objective: To assess the impact of climate change on egg production, growth, health and survivability of poultry

Impact of climate change on survivability, body temperature, respiration, and feed consumption

Mortality data among improved meat and egg type chickens and native (rural) type chickens reared under intensive management conditions for six years (2004-2009) was analyzed in relation to ambient temperature. Monthly average mortality and mortality due to heat stress were calculated. Body temperature (rectal) was recorded using a digital thermometer rectal probe and respiratory rate was recorded by holding the bird in hands and observing the expansion and contraction of thoracic cavity and expressed as number per minute. Temperature and respiratory rates were recorded at every one degree centigrade rise in shed temperature from 28-42°C. Weekly feed intake in relation to house temperature was calculated.

Impact of climate change on egg production

Climate change, particularly increased temperature is likely to have a significant effect on the production and survivability in poultry flocks. Egg production in broiler breeder and commercial layer farms was assessed and compared with standard egg production of respective breeder/layer flocks. These results indicate that the heat stress caused by high environmental temperature causes significant economic losses due to high mortality and reduced egg production.

Effect of ambient temperature on semen quality in chicken

Semen quality of naked neck and dwarf chicken was studied in relation to ambient temperature. Semen was collected from 24 weeks to 48 weeks of age at 4 week interval and evaluated for different parameters like volume, appearance, motility, concentration, fertilizing ability, live sperm, dead sperm and abnormal sperm. The mean ambient temperature at the start of experiment was 33.4° C and declined to 24.9°C at 48 weeks of age of birds.

Emission of methane, nitrous oxide and ammonia from poultry

Poultry egg and meat production data was obtained from FAO statistics. The total emission of methane, nitrous oxide and ammonia per total egg and poultry meat was calculated using reference values for eggs and meat produced during year 1070, 1980, 1990, 2000, and 2008 and expressed in tons.

Salient findings

Effect of temperature on survivability of broiler, layer and desi chicken

The analysis of mortality data from 2004 to 2009 revealed that the over all mortality was increased as the ambient temperature rises in broiler, layer and native chickens (Fig.139). The mortality started increasing when the temperature reaches 32°C and the peek was observed at 38 to 39°C (13.5%). The mortality was highest in broiler type chickens followed by layers and native chicken. The mortality due to heat stress in broiler type birds was started appearing at the ambient temperature 30°C, while in layer and native chicken the heat stress related mortality was observed at the ambient temperature of 31°C. The deaths due to heat stress were 10 times more in broiler type chickens as compared to layer and native type chickens (Fig.140). The mortality due to heat stress was negligible in native (Desi type chickens) which may be due to low metabolic rate and natural heat tolerance.

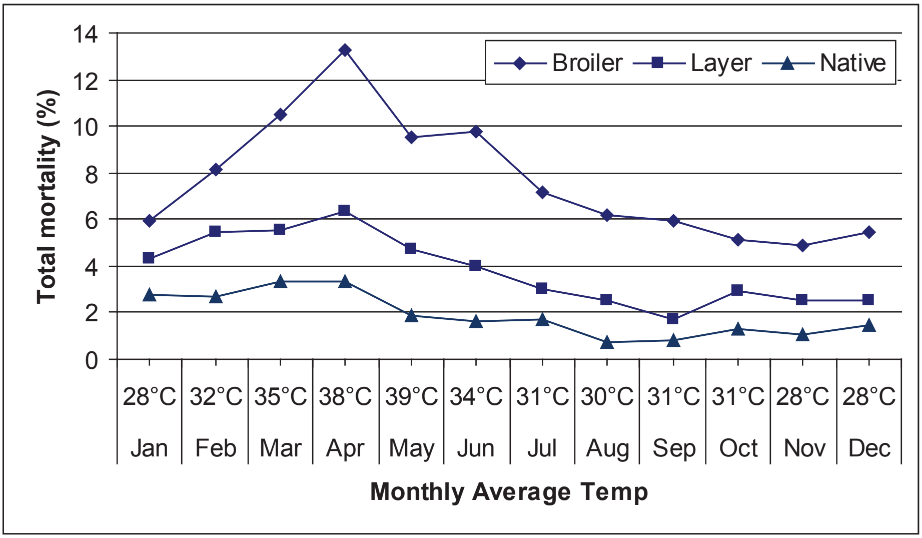


Fig.139. Effect ambient temperature on the survivability of meat type (broiler), egg type (layer) and native (desi) chicken

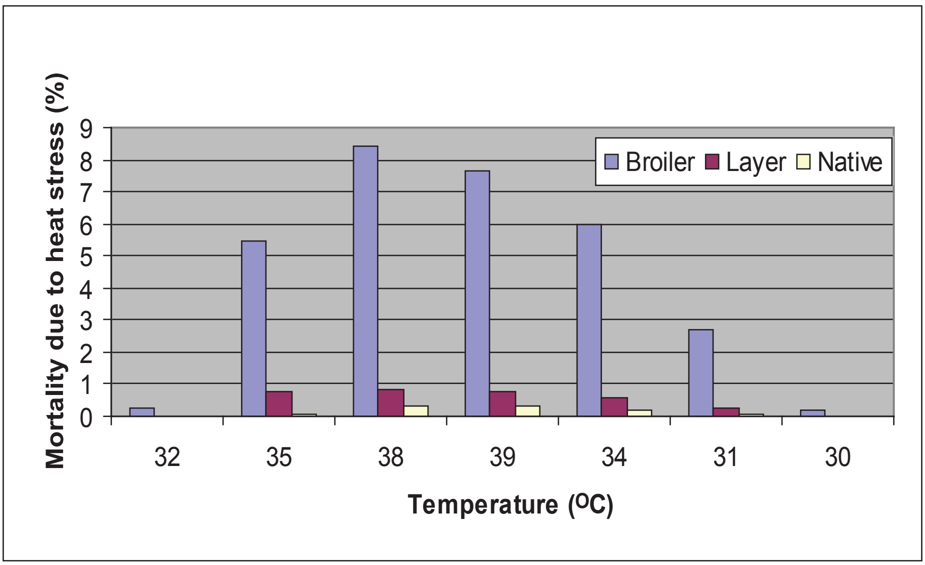


Fig. 140. Mortality due to heat stress caused by high ambient temperature

Effect of elevated temperature on egg production, feed intake, respiratory rate and body temperature

Climate change particularly increased ambient temperature is likely to have a significant effect on production performance of poultry populations. High environmental temperature is one of the most serious factors effecting the production performance of broiler and layer chickens. The production data analyzed in relation to ambient temperatures inside the poultry house revealed that the egg production in broilers was started drop at 34°C and the drop was persistent during the period where the temperatures were higher than 32°C. the drop was 3 to 6% less than the standard production of that particular breed of broiler parents (Fig.141). Similarly in commercial layers the drop in egg production during high ambient temperatures was recorded up to 7% lower than to standard egg production of that particular breed (Fig.142).

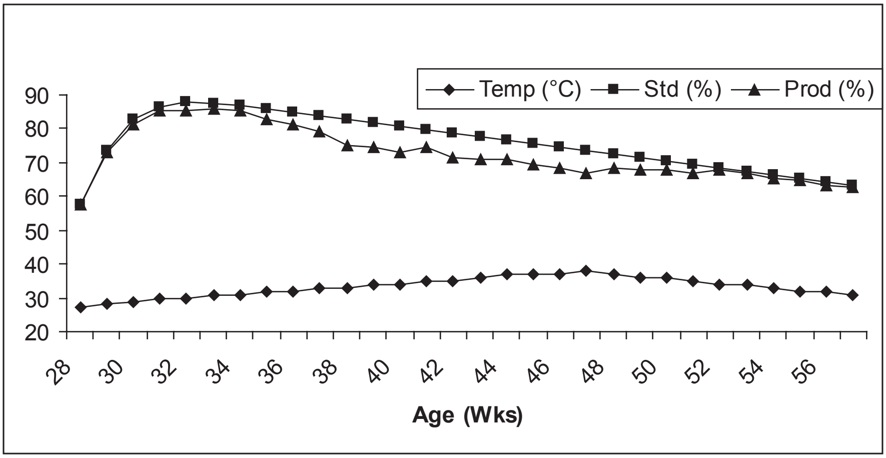


Fig.141. Effect of shed temperature on egg production in broiler breeders

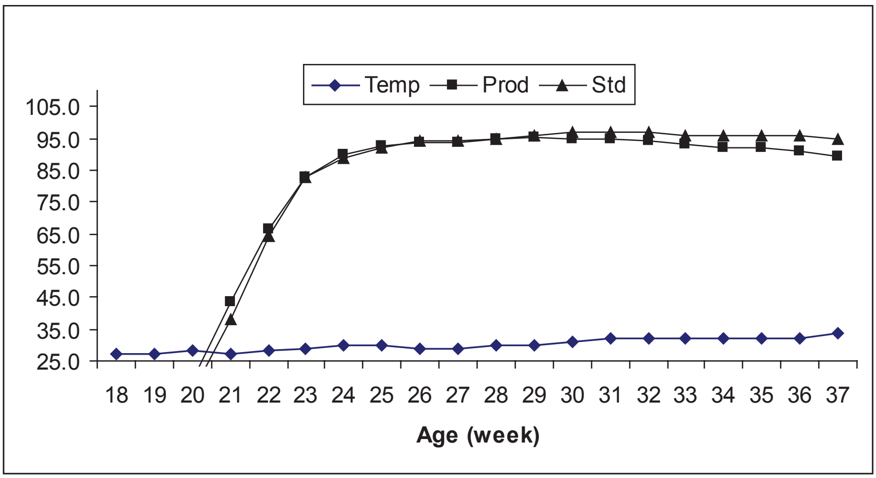


Fig.142. Effect of shed temperature on egg production in commercial layers

Influence of high ambient temperature on feed intake body temperature and respiratory rate

The body temperature recorded was 41°C at the shed temperature of 28°C and gradually increased to 45°C at 42°C of shed temperature. The rate of increase was higher between 38 and 42°C of shed temperature (Fig.143). in this study the critical temperature at which the birds succumb to death was 45°C observed at the shed temperature 42°C. The respiratory rate at 6 weeks of age was recorded for every 1°C rise in shed temperature (28 to 42 °C). At 28 C the respiratory rate was 46 for minute while at 42°C the respirations observed were 150 per minute (Fig.144). The average daily feed intake, the maximum shed temperature and humidity were recorded in commercial layers for 13 weeks. The consumption which was 108 gm/bird/day at 28°C was reduced to 68 gm/bird/day at the shed temperature 37.8°C (Fig.145)

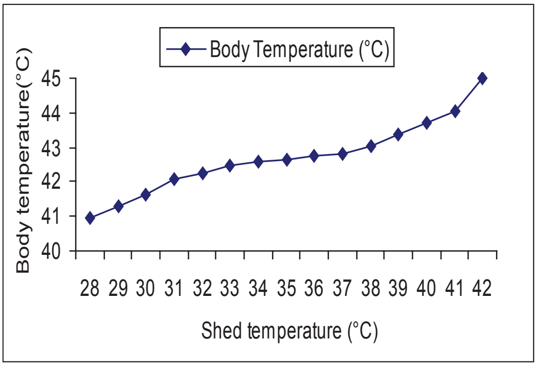


Fig.143. Effect of temperature on body temperature in broiler chicken (6wks)

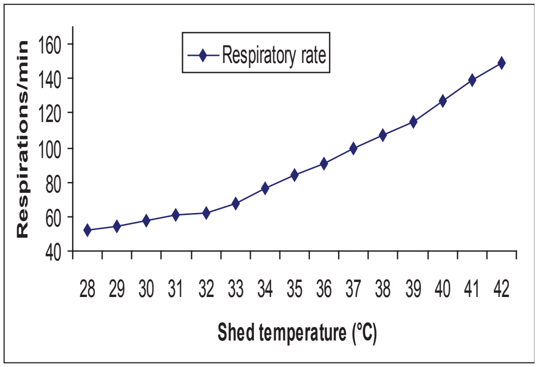


Fig. 144. Effect of temperature on respiratory rate in broiler chicken (6wks)

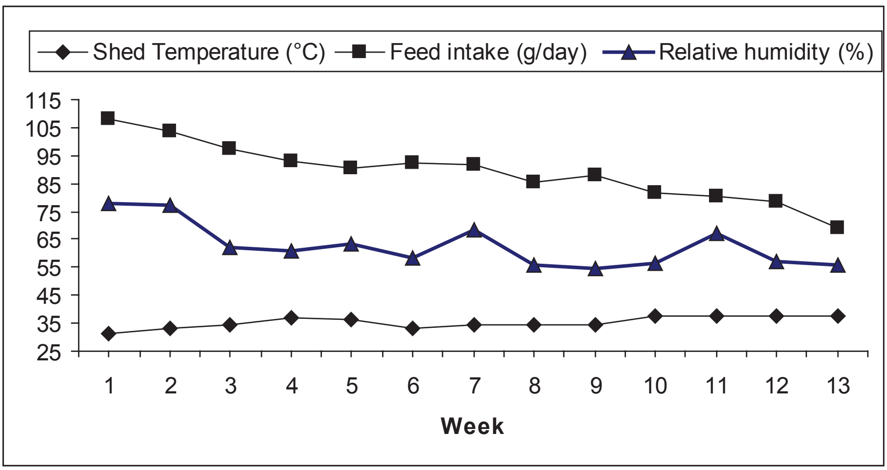


Fig.145. Influence of elevated ambient temperature on feed consumption

Effect of ambient temperature on semen quality in chicken

The fertilizing ability of spermatozoa as determined MTT reduction assay was found to decrease significantly ($p<0.05$) with increase in shed temperature. The number of dead spermatozoa was increased with increase in shed temperature (Table 72). A significant ($P<0.05$) negative correlation was observed between mean ambient temperature and live sperms in both the types of chicken. The volume of sperms and fertilizing ability was negatively correlated in naked neck chicken, whereas individual motility was negatively correlated ($P<0.05$) with ambient temperature in dwarf chicken.

Table 72. Effect of raise in ambient temperature on semen quality of chicken lines naked neck (NN) and Dwarf (DW)

Mean ambient temperature	Fertilizing ability (nm formazan /min/ million sperm)		Live sperms (%)		Dead sperms (%)		Abnormal sperms (%)	
	NN	DW	NN	DW	NN	DW	NN	DW
33.4	19.91 ± 3.29 [b]	17.08 ± 1.22 [c]	80.37 ± 5.17 [c]	85.37 ± 1.98[b]	20.53 ± 5.31 [a]	14.63 ± 1.98 [a]	0.72 ± 0.32 [a]	0.23 ± 0.09 [bc]
32.5	24.47 ± 1.38 [ab]	22.69 ± 1.53 [b]	87.66 ± 1.83 [ab]	85.83 ± 2.93[b]	12.34 ± 1.83 [b]	14.16 ± 2.93 [a]	0.16 ± 0.10 [b]	0.42 ± 0.17 [ab]
29.2	20.98 ± 2.64 [b]	22.68 ± 1.79 [b]	85.94 ± 1.14 [bc]	87.25 ± 1.45[b]	14.06 ± 1.14 [b]	12.74 ± 1.45 [a]	0.1 ± 0.07 [b]	0.08 ± 0.08 [c]
28.6	25.41 ± 1.50 [ab]	23.77 ± 0.89 [b]	86.25 ± 1.84 [abc]	87.55 ± 1.27[b]	13.75 ± 1.84 [b]	12.44 ± 1.27 [a]	0.38 ± 0.16 [ab]	0.09 ± 0.04 [c]
25.4	29.75 ± 1.48 [a]	30.62 ± 0.74 [a]	89.32 ± 1.11 [ab]	92.26 ± 0.97[a]	10.67 ± 1.11 [b]	7.74 ± 0.97 [b]	0.43 ± 0.15 [ab]	0.40 ± 0.12 [abc]
27.8	25.58 ± 3.31 [ab]	29.27 ± 2.13 [a]	87.13 ± 1.13 [ab]	94.61 ± 0.61 [a]	12.87 ± 1.14 [b]	5.38 ± 0.61 [b]	0.83 ± 0.17 [a]	0.12 ± 0.06 [bc]
24.9	30.04 ± 3.37 [a]	21.71 ± 1.11 [b]	92.48 ± 0.66 [a]	93.18 ± 0.44 [a]	7.51 ± 0.66 [b]	6.81 ± 0.44 [b]	0.41 ± 0.15 [ab]	0.67 ± 0.11 [a]

Emission of methane, nitrous oxide and ammonia from poultry

Because poultry is non-ruminant and non-herbivorous, the methane emission from enteric fermentation of poultry is below 1% of the total methane emission from animal sector. The production of poultry eggs and poultry meat in India and emission levels of methane, nitrous oxide and ammonia are presented in Table 73.

Table 73. Emission of methane, nitrous oxide and ammonia from poultry

Year	Poultry eggs (tons)	Emissions (tons)			Poultry Meat (Tons)	Emissions (tons)		
		Methane (CH_4)	Nitrous Oxide (N_2O)	Ammonia (NH_3)		Methane CH_4	Nitrous Oxide N_2O	Ammonia NH_3
1970	290000	2175	1102	8120	93219	457	3169	2144
1980	583000	4373	2215	16324	132150	648	4493	3039
1990	1161000	8708	4412	32508	371510	1820	12631	8545
2000	2015000	15113	7657	56420	1135900	5566	38621	26126
2008	2740000	20550	10412	76720	2562800	12558	87135	58944

Farmers awareness program on climate change

One day awareness seminar on "Climate change and possible impacts on poultry industry" was organized on 27th March 2010 at Project Directorate on Poultry. Poultry farmers, industry people, poultry consultants, scientists and students were attended the seminar. Lectures from experts covering general aspects of climate change, impacts on poultry, nutritional, housing and management strategies to overcome the effects of climate change were arranged. Farmers interacted experts and clarified their doubts about climate change and its impacts and strategies to overcome ill effects. A write-up was prepared and distributed to all the participants.

Objective: To document Indigenous knowledge in relation to climate change relevant to poultry production

Salient findings

Indigenous technical knowledge relevant to climate change based on accumulated experiences of farmers and other people were collected. Some ITKs and practices being adapted to treat heat and cold stress caused by climatic change are presented in table 74.

Table 74. Indigenous technical knowledge practices relevant to climate change in poultry

Name of ITK	Practical utility
Goose berry (*Emblica officinalis*)	Its fruits is a rich source of Vitamin C used in treatment of stress conditions including heat stress
Storage of fertile eggs in a pot containing sand	Provide cooling effect which prevents spoilage of fertile eggs during high ambient temperatures.
Garlic (*Allium sativum*)	Used in treating pulmonary conditions like respiratory distress.
Sea buck thorn (*Hippopae rhamnides*)	Its fruit is a rich source of Vitamin C (1250mg/100g), used in heat and cold stress conditions.

Name of ITK	Practical utility
Drumstick tree (*Moringa pterygosperma*)	Leaves are rich in Vitamin A and C, used as anti stress medication
White mulberry (*Morus alba*)	Leaves are good source of ascorbic acid (300mg/100g)
Tinospora cardifolia (Gulancha tinospora)	Antipyretic, anti inflammatory and anti viral (Ranikhet disease) properties
Onion and turmeric	Used in curing coccidiosis in poultry
Water batting	Frequent water bathing for reducing broodiness
Jaggery water	Used to prevent stress related to heat, cold and transportation

Objective : To identify various management and nutritional strategies for adaptation to climate change

Identification of strategies for adaptation to climate change

Literature search was conducted on impact of climate change and possible strategies to adapt poultry to changing climatic conditions. Expert opinion about climate change adaptation strategies was gathered from experts in Poultry science by personal contacts. Data on adaptation strategies was compiled based on the literature survey and expert consultation.

Naked neck chicken is able to tolerate heat

Experiments were conducted to study the suitability of naked neck gene under tropical environments and its utilization as alternate variety for broiler production in the event of increased environmental temperature and humidity. The experiment was conducted in two season's winter and summer as environmental chambers are not available to simulate different temperature ranges. However the present experiment will provide useful information regarding the adaptability of naked neck birds at high temperatures. The present experiment aimed at studying the performance of broiler based Naked neck chicken in comparison to their normal siblings. A total of 470 (55 normal and 415 Naked neck) and 420 (60 normal and 360 Naked neck) chicks in winter and summer season were produced in a random mating using 20 sires and 100 dams and reared up to 6 weeks of age in battery brooders. The birds were randomly distributed in brooder cages to eliminate the confounding effects of the environment. The birds were fed with broiler starter ration with 2900 ME and 22 CP up to 3 weeks of age and broiler finisher diet with 3000 ME and 20 CP from 4 to 6 weeks of age.

Identification of strategies to adapt climate change

Increased ambient temperature due to global warming is a major concern to poultry industry in future. Various potential managemental, nutritional and breeding strategies to alleviate heat stress due to climate change are presented in Table 75.

Table 75. Breeding, nutrition and management strategies to adapt changing climatic conditions

1) Management strategies	
A) Roof treatment	1. Light reflection by painting 2. Insulation with roof cover with straw
B) Evaporative cooling in Open sided house	1. Housing with width and height adjustments 2. Applying water to the outside of the building 3. In house fogging 4. Wet curtains/gunny bags on the sides of the house
C) Evaporative cooling in Open sided house	1. Cooling pads and fans 2. Tunnel ventilation systems
D) Husbandry practices	1. Reducing flock density 2. Providing cool drinking water and adequate drinkers 3. Feeding management-restriction, changing the feeding time
E) Epigenetic adaptation to environment	1. Prenatal epigenetic thermal conditioning 2. Early postnatal epigenetic thermal conditioning
2) Breeding strategies	
A) Selection for heat tolerance	1. Long term selection for heat tolerant lines
B) Use of major genes	1. The naked neck gene lines 2. Frizzle gene lines 3. Dwarf gene lines
3) Nutritional strategies	
A) Maintaining feed in take, electrolyte and water balance	1. Manipulation of dietary energy, protein and amino acid composition 2. Supplementation of electrolytes
B) Supplementation of micronutrients	1. Supplementation of vitamins and minerals 2. Supplementation of probiotics

Evaluation of thermotolerance of naked neck chickens as an adaptation strategy to elevated temperature due to climate change

The analysis of the data revealed that during the winter trail, the body weights did not show any significant difference at later stages 4 and 5 weeks of age, however it was significant at 1st and 3rd weeks of age. The performance of Normal birds was numerically higher compared to the naked neck birds during the winter season. Weight gain also showed similar trend, it was significant only at 1st week of age. The summer trial showed significant differences between the body weights at all ages except for day old body weight. Naked neck birds recorded significantly higher body weights at 1st, 2nd, 3rd, 4th 5th and 6th week body weights. Daily weight gains also showed similar trend, the weight gains were significantly varied between the normal and naked neck birds from second week onwards. FCR was not significant during the experimental period in naked neck and Normal birds except at third week of age in normal chicken. However the FCR was better in naked neck birds during summer season compared to normal birds whereas in winter it was better in normal chicken (Table 76).

The immune competence of the two groups was studied in winter and summer season at 6 weeks of age. In winter SRBC titers showed significant variation. During summer immune parameters were not significantly varied among the normal and naked neck birds, however the magnitude of the titers was higher for SRBC and the antibody response to PHA-P was lower during the summer season. The proportion of heterophils decreased in Naked neck chicken during the summer indicating the heat tolerance capacity of the birds whereas it was not true in case of normal chicken (Table 77). The haemoglobin concentration varied significantly between the normal and Naked neck chicken during summer season while it was not significant during the winter. The significant higher levels of Lipo peroxidase enzyme during summer reveals that there was oxidation of fat resulting in excess energy utilization. The increase of GPx and GR levels in both groups during summer indicates the stress condition of the birds. As age advance LP and GPx reduced and GR increased in different seasons. The changes in concentration of enzymes with age reveal that the birds are under increased stress as age advances. In Naked neck birds the dressing percentage was significantly higher compared to the normal birds because of lack of feathers around neck region.

An experiment was conducted to study the effect of energy levels on the performance of Naked neck chicken. Three diets with 2750 (T1); 2850 (T2) and 2950 (T3) energy levels were prepared and fed adlibitum to the birds. The analysis of the data revealed that there was no significant difference in body weight up to 6 weeks of age, weight gains and FCR at different ages. This clearly shows that low energy diet is sufficient for the optimum performance of the birds which will reduce the cost of feed.

Table 76. Performance of Naked neck and normal birds in high and low ambient temperatures

Parameter	Low temperature (12-19°C)		High temperature (34-40°C)	
	Normal	Naked neck	Normal	Naked neck
Weight gain (g)				
4th week	617.26	584.36	506.16 [b]	550.73 [a]
5th week	816.76	786.81	767.85 [b]	828.97 [a]
6th week	1145.43	1084.56	924.66 [b]	1009.69 [a]
Feed Conversion Ratio				
4th week	1.74	1.75	1.66	1.66
5th week	1.90	1.90	1.70	1.75
6th week	1.93	1.90	1.90	1.88

Table 77. Immune, blood biochemical parameters in Naked neck and normal chicken during winter and summer at 6 weeks of age

Parameter	Low temperature (12-19°C)		High temperature (34-40°C)	
	Normal	Naked neck	Normal	Naked neck
Antibody titers to SRBC (log2)	2.6^{b}	3.5^{a}	6.67	6.73
Antibody titers to ND (log2)	6.2	6.7	5.0	5.2
PHA-P (mm)	2.34	2.74	1.4	2.06
H:L Ratio	0.39^{b}	0.45^{a}	0.71^{y}	0.62^{x}
Hemoglobin	9.32	9.15	8.6^{y}	9.2^{x}
PCV	27.93	27.5	26.13^{y}	27.8^{x}

These results clearly substantiate the heat tolerance capacity of the naked neck birds that perform well on low energy diets which is economical to the farmer. These birds could be a potential resource under the circumstances of increased environmental temperatures because of global warming.

TOCKLAI EXPERIMENTAL STATION
TEA RESEARCH ASSOCIATION
JORHAT

Objective : To study the effect of elevated CO_2 and temperature on tea biomass production and quality of different tea cultivars

The level of atmospheric CO_2 in and around Tocklai Experimental Station, Jorhat, Assam has been increasing at the rate of 1.5 ppm per annum. Keeping this in view, tea leaf was fed with 350, 550, 750, 950, 1150 and 1350 ppm of CO_2 and rate of carbon assimilation was recorded by using the Infra Red Gas Analyzer (IRGA) of PP system (CIRAS I). A carbon-dioxide cartridge of 2000 ppm capacity was loaded in the IRGA and required concentration of CO_2 was released sequentially to the leaf chamber. Other physiological attributes like leaf temperature, transpiration loss and water use efficiency of the plant were also estimated. Field grown plants of 31 varieties from TV1 to TV31 were undertaken in this study. To minimize the variation that may occur (due to influence of other atmospheric factors like air temperature, light intensities, humidity etc,), all metabolic activities were recorded within 10 -11 hours of the day. The physiological attributes were recorded in the field. To study the biochemical attributes of tea plants proline, chlorophyll a and b were also studied and methods standardized, so that all these attributes can be quantified under the controlled conditions.

Table 78. Effect of elevated CO_2 on photosynthesis

Clone	Photosynthesis (µmol $m^{-2}s^{-1}$)						
	CO_2 Concentration (ppm)						
	350 ppm	550 ppm	750 ppm	950 ppm	1150 ppm	1350 ppm	Mean
TV1	16.1	19.3	28.8	28.2	31.6	26.0	25.0
TV2	14.4	18.3	28.7	28.9	28.4	22.0	23.5
TV3	13.3	20.9	28.7	26.2	24.9	21.9	22.7
TV4	13.6	20.8	28.3	27.5	27.3	24.0	23.6
TV5	12.8	21.4	26.6	28.4	31.4	23.8	24.1
TV6	10.4	20.4	24.4	28.6	34.3	22.0	23.4
TV7	12.5	21.7	22.2	28.4	32.3	23.8	23.5
TV8	13.4	21.7	20.9	26.7	30.7	29.1	23.8
TV9	13.5	22.3	22.4	28.0	29.5	22.7	23.1
TV10	15.8	20.5	24.9	30.5	32.1	26.0	25.0
TV11	13.7	20.5	24.9	27.3	25.4	29.9	23.6
TV12	14.0	20.6	23.2	27.3	27.7	22.3	22.5

Clone	Photosynthesis (µmol $m^{-2}s^{-1}$)						
	CO_2 Concentration (ppm)						
	350 ppm	550 ppm	750 ppm	950 ppm	1150 ppm	1350 ppm	Mean
TV13	14.7	19.3	24.4	27.7	27.3	29.8	23.9
TV14	13.3	21.5	24.0	26.4	29.3	27.9	23.7
TV15	14.4	21.1	21.6	26.6	28.3	26.0	23.0
TV16	14.4	21.3	23.4	25.9	30.2	23.8	23.2
TV17	13.3	21.1	23.6	29.0	29.0	28.9	24.2
TV18	15.4	20.4	23.0	32.3	33.1	32.8	26.2
TV19	15.9	21.6	22.8	28.4	29.8	30.2	24.8
TV20	16.0	20.2	21.2	28.2	25.7	25.6	22.8
TV21	15.5	22.3	18.9	26.1	24.9	27.7	22.6
TV22	15.3	21.1	18.6	27.5	22.8	28.6	22.3
TV23	14.1	20.4	21.9	27.7	26.1	22.3	22.1
TV24	14.1	21.2	22.2	26.2	28.4	24.9	22.8
TV25	14.2	21.5	21. 9	28.1	28.1	25.9	23.6
TV26	15.0	20.3	22.6	27.3	34.4	26.3	24.3
TV27	14.3	21.0	20.3	26.5	36.5	21.6	23.4
TV28	15.3	21.5	20.5	27.1	31.2	23.4	23.2
TV29	15.7	22.1	25.6	28.3	31.4	26.9	25.0
TV30	16.1	20.5	21.0	29.2	33.4	25.0	24.2
TV31	16.4	19.5	20.1	28.8	30.8	26.2	23.6
Mean	14.42	20.85	23.32	27.85	29.56	25.72	23.88

The photosynthetic efficiency gradually increased from the lower to higher concentrations of CO_2 till it reached 1150 ppm. Thus, it appeared that the tea plants will withstand much more (higher) CO_2 than the prevailing (Current= 364ppm at Jorhat, Assam) atmospheric CO_2 (Table 78).

Table 79. Effect of elevated CO_2 on transpiration loss

Clone	Transpiration (m mol $m^{-2}s^{-1}$)						
	CO_2 Concentration (ppm)						
	350 ppm	550 ppm	750 ppm	950 ppm	1150 ppm	1350 ppm	Mean
TV1	2.30	1.81	1.87	2.06	2.17	2.57	2.1
TV2	2.89	1.56	1.82	2.92	2.62	2.94	2.5
TV3	2.86	2.12	1.84	2.93	2.61	3.02	2.6
TV4	2.69	1.77	1.86	3.0	2.93	3.44	2.6
TV5	2.93	2.93	1.89	2.84	2.81	3.11	2.8
TV6	1.76	2.76	1.88	3.03	3.12	2.95	2.6
TV7	1.65	2.45	1.93	2.04	2.37	2.3	2.1
TV8	3.06	1.93	2.05	2.73	2.55	3.26	2.6
TV9	1.80	2.40	1.66	2.20	2.25	2.34	2.1
TV10	2.17	2.55	1.50	2.10	2.67	2.84	2.3
TV11	3.13	2.26	1.52	2.64	2.87	2.28	2.5
TV12	2.78	2.99	1.89	1.88	3.10	2.99	2.6
TV13	2.94	2.94	2.16	2.96	2.93	3.34	2.9
TV14	2.39	2.99	2.20	2.29	2.99	2.62	2.6
TV15	3.36	3.16	1.86	2.65	2.96	2.73	2.8
TV16	2.51	2.93	1.96	1.93	2.80	2.68	2.5
TV17	2.47	2.81	2.05	2.72	2.62	2.75	2.6
TV18	2.48	2.74	2.00	2.85	2.17	3.68	2.7
TV19	2.57	2.96	2.08	2.18	2.10	2.80	2.4
TV20	2.53	2.85	1.99	2.82	2.67	3.02	2.6
TV21	3.04	3.04	1.76	2.84	1.63	3.50	2.6
TV22	2.49	2.84	1.67	2.14	1.93	4.55	2.6
TV23	2.33	2.97	1.71	2.19	1.75	3.80	2.5
TV24	2.50	3.10	1.62	2.23	1.93	2.80	2.4
TV25	2.22	3.02	1.61	1.93	2.32	2.64	2.3
TV26	2.39	2.83	1.49	2.32	2.00	3.05	2.3
TV27	1.82	2.51	1.35	1.97	2.03	2.48	2.0
TV28	1.70	2.31	1.87	2.66	2.07	2.80	2.2
TV29	2.05	2.06	1.64	2.27	2.13	3.26	2.2
TV30	1.91	2.45	1.34	2.37	1.92	3.08	2.2
TV31	1.73	2.35	1.52	2.37	2.13	2.08	2.0
Mean	2.43	2.59	1.79	2.45	2.42	2.96	2.44

The transpiration loss due to elevated CO_2 did not very much. However, more accuracy may be observed under OTC, whenever it is made available. Clonal variation appeared to be the minimum (Table 79).

Table 80. Effect of elevated CO_2 on water use efficiency

Clone	Water Use Efficiency (WUE)(µ mol/m mol)						
	CO_2 Concentration (ppm)						
	350 ppm	550 ppm	750 ppm	950 ppm	1150 ppm	1350 ppm	Mean
TV1	7.01	10.45	15.38	13.98	14.70	10.19	11.95
TV2	5.00	11.73	15.78	9.96	10.90	7.48	10.14
TV3	4.67	9.86	15.59	8.96	9.58	7.28	9.32
TV4	5.07	11.76	15.52	9.15	9.41	6.99	17.26
TV5	4.37	7.30	14.06	10.07	11.20	7.64	9.11
TV6	5.91	7.37	13.00	9.50	11.07	7.37	7.09
TV7	7.67	8.87	11.53	14.2	13.70	10.35	11.05
TV8	4.42	11.04	10.18	9.82	12.17	8.94	9.43
TV9	7.58	9.28	13.53	12.73	13.14	9.91	11.03
TV10	7.25	8.04	16.59	14.55	12.63	9.18	11.37
TV11	4.37	9.06	13.68	10.44	9.48	13.15	10.03
TV12	5.07	6.87	12.23	14.54	9.70	7.47	9.31
TV13	5.02	6.55	11.28	9.38	8.82	8.95	8.33
TV14	5.67	7.19	10.93	11.59	10.08	10.67	9.36
TV15	4.30	6.66	11.62	10.08	9.49	9.70	8.64
TV16	5.82	7.26	11.93	1.046	10.26	8.92	7.54
TV17	5.47	7.52	11.48	10.66	10.42	11.17	9.45
TV18	6.23	7.45	11.46	11.31	12.82	8.95	9.70
TV19	6.20	7.30	10.95	13.13	13.79	10.93	10.38
TV20	6.36	7.08	10.66	10.08	12.32	8.55	9.18
TV21	5.11	7.30	10.73	9.20	9.35	7.89	8.26
TV22	6.17	7.87	11.17	12.91	14.04	6.30	9.74
TV23	6.15	7.11	12.79	12.85	13.71	5.88	9.75
TV24	5.66	6.58	13.67	11.79	16.28	8.90	10.48
TV25	6.44	7.03	13.65	14.48	14.66	9.84	11.02
TV26	6.31	7.61	15.23	11.84	15.08	8.64	10.79
TV27	7.90	8.09	14.96	13.45	18.33	8.70	11.91
TV28	9.04	9.19	10.96	10.23	15.24	8.80	10.58
TV29	7.71	8.69	15.6	12.55	14.73	8.33	11.27
TV30	8.79	7.84	15.65	12.31	17.44	8.50	11.76
TV31	9.55	8.15	13.23	12.12	14.58	12.72	11.73
Mean	7.67	8.20	12.69	11.26	12.55	8.98	10.22

The water use efficiency increased with the increased CO_2 concentrations. However the optimum level of WUE was at 1150 ppm of CO_2 (Table 80).

Table 81. Effect of elevated CO_2 on leaf temperature (^{O}C)

Clone	*CO_2 Concentration (ppm)*						
	350 ppm	**550 ppm**	**750 ppm**	**950 ppm**	**1150 ppm**	**1350 ppm**	**Mean**
TV1	28.6	30.2	29.5	30.2	31.6	32.1	30.4
TV2	28.6	30.5	29.5	30.5	30.2	31.8	30.2
TV3	28.6	29.6	30.6	29.6	30.5	31.2	30.0
TV4	28.7	29.6	30.6	29.6	29.6	31.4	29.9
TV5	25.7	29.3	29.7	29.3	29.6	31.8	29.2
TV6	23.1	29.3	22.8	29.3	29.3	29.9	27.3
TV7	23.5	30.3	29.3	30.3	29.3	31.9	29.1
TV8	23.3	30.3	29.3	30.3	30.3	31.7	29.2
TV9	22.7	30.3	28.1	30.3	30.3	29.8	28.6
TV10	22.9	30.4	28.1	30.4	30.3	29.9	28.6
TV11	23.6	30.2	29.1	30.2	30.4	31.4	29.1
TV12	23.9	30.2	29.5	30.2	30.2	30.1	29.0
TV13	23.6	30.3	29.5	30.3	30.2	30.5	29.1
TV14	23.0	30.2	29.5	30.2	30.3	30.7	29.0
TV15	22.9	29.1	29.5	30.3	30.2	30.7	28.8
TV16	22.4	29.2	29.3	30.2	29.9	30.4	28.6
TV17	22.2	28.6	27.4	30.3	30.0	30.2	28.1
TV18	22.0	28.6	29.3	30.2	29.9	30.2	28.4
TV19	22.1	29.8	29.8	30.3	26.4	30.3	28.1
TV20	22.2	28.3	29.9	30.2	26.2	29.4	27.7
TV21	22.2	30.1	30.1	26.7	24.7	30.8	27.4
TV22	23.5	30.2	30.6	30.3	25.4	30.8	28.5
TV23	23.5	30.9	30.9	30.2	25.6	30.3	28.6
TV24	22.0	30.1	30.1	26.7	25.7	30.4	27.5
TV25	21.3	29.4	29.4	30.3	25.6	30.1	27.7
TV26	20.9	29.4	29.4	30.2	25.2	29.7	27.5
TV27	22.9	29.3	29.3	30.3	25.6	30.6	28.0
TV28	24.7	29.3	29.3	30.2	25.6	29.4	28.1
TV29	22.2	29.4	30.9	30.2	25.6	29.4	28.0
TV30	22.2	29.3	29.3	25.5	25.6	29.9	27.0
TV31	25.3	29.3	30.7	26.9	25.6	25.6	27.2
Mean	23.7	29.7	29.4	29.7	28.2	30.4	28.5

Leaf temperatures remained almost constant between 550ppm to 1150 ppm of CO_2 concentrations. The leaf temperature became higher at 1350 ppm (Table 81).

Variations of quality parameters between organic and inorganic treatments

Leaf samples from the plots treated with organic manures as well as from control (Inorganic) plots were processed to produce the black tea. Biochemical parameters i.e. theaflavin (TF), thearubigin (TR) etc. in relation to quality were analyzed to see whether there is any variation of quality parameter. Planting materials used in this experiment are mostly TV-Clone and Assam Jats. Significant variation of quality parameters was observed (Table 82). Theaflavin contents responsible for brightness and briskness were found to be higher in the black tea processed from the leaf treated with organic matter. Similarly another quality parameter, low molecular wt. thearubigin (TR1) was found to be higher for the same. Overall cup character in terms of brightness, briskness, strength etc. of the made tea from organic treatment were found to be superior in comparison to inorganic.

Table 82. Effect of organic treatment on quality

S. No	Organic					Control (Inorganic)				
	%TF	%TR1	%TR2	%TR(t)	%B	%TF	%TR1	%TR2	%TR(t)	%B
1	1.56	5.62	11.25	16.87	15.23	1.38	4.26	10.85	15.11	13.45
2	1.62	5.23	12.15	17.38	15.65	1.42	3.85	11.18	15.05	15.65
3	1.49	6.25	11.15	17.40	14.25	1.28	3.95	12.25	16.20	13.25
4	1.65	4.95	12.16	17.11	16.25	1.42	4.25	11.26	15.51	14.25
5	1.58	5.45	10.25	15.60	15.45	1.35	3.62	11.25	14.87	13.16

Objective: To identify the potential adaptation strategies and subsequently evaluate them in terms of yield, quality and carbon sequestration

A series of experiments were started in laboratory, glasshouse as well as in the field:

(i) Pot culture experiment

A pot culture experiment was carried out to study the effect of organic manures on the buildup of soil organic matter and their influence on dry matter production. The pot culture experiment was carried out in the glass house at Tocklai Experimental Station, Jorhat. Earthen pots of 12 inch diameter were filled with 10 kg of sandy loam soil with pH value 4.8 and planted with one year old tea plants of clone T_3E_3 in June, 2009. Before planting the tea plants in pots, the soil was treated with cattle manure (CM), vermicompost (VC) and Neem cake (NC) each @ 5, 10, 20 and 40 t/ha. A control pot was also maintained.

(ii) Incubation experiment

The mineralization of three organic manures viz. Vermicompost (VC), cattle manure (CM) and neem cake (NC) in tea soil was studied in a laboratory incubation experiment for 10 weeks at 75 per cent field capacity moisture and at 32 ± 2^0C temperature. CO_2 produced was measured by absorbing it in NaOH and followed by back titration against 0.1N HCl following the procedure of Isermeyer (1952). The cumulative CO_2-C data were subjected to first order kinetics carbon mineralization model to obtain the mineralization rate constants and half life.

(iii) Field experiment

A field experiment was laid out at Tocklai Experimental Station during 2009 in mature tea section (field) to see the effect of application of vermicompost on build up of different fractions of organic matter in soil and its effect on yield. Treatments included 0, 5, 10, 20 and 40 t vermicompost/ha with three replicates in a randomized complete block design. Treatments in the experimental plots were imposed during 2009. Before imposition of treatments, soil samples were collected from the experimental plots for monitoring the bench mark status on soil organic carbon fractions and microbiological parameters.

Organic carbon content of soil was determined by wet digestion method (Walkley and Black's titration method) (Jackson,1973). For extraction and separation of the humic substances the method of Kononova (1966) and Page *et al.* (1982) was followed. The extracted humic acid (HA) and fulvic acid (FA) were purified following the method described by Schnitzer and Khan (1978). The humus carbon and humic acid carbon (HAC) were determined by Walkley and Black's titration/or wet combustion method (Jackson, 1973).

Findings

(i) Effect of organic manures on soil organic carbon, humus carbon and plant biomass

Application of the organic manures increased organic carbon and humus carbon in soil (Table 83 & 84). Both Vermicompost and cattle manure maintained higher organic carbon and humus carbon as compared to decomposed neem cake. For build up of carbon (Stable pool humus) in soil the organic manures can be arranged as VC>CM>NC.

Table 83. Organic C (%) in soil treated with different organic manure

Treatments	Rate of application				Mean
	5t/ha	10 t/ha	20t/ha	40 t/ha	
Control	0.77	0.77	0.76	0.78	0.77
VC	0.78	0.86	0.96	1.20	0.95
CM	0.78	0.82	0.92	1.15	0.92
NC	0.77	0.80	0.88	0.90	0.84
Mean	0.77	0.81	0.88	1.00	
C.D. ($P < 0.05$)					
Treatment mean	0.01				
Rate mean	0.01				
Treatment x rate	0.03				

Table 84. Humus C (%) in soil treated with different organic manure

Treatments	Rate of application			
	5t/ha	10 t/ha	20t/ha	40 t/ha
Control	0.394	0.395	0.397	0.397
VC	0.418	0.450	0.493	0.552
CM	0.398	0.446	0.474	0.520
NC	0.398	0.421	0.430	0.440

Table 85. Total biomass (g/plant) of tea plants under different organic manure treatments

Treatments	Rate of application				Mean
	5t/ha	10 t/ha	20t/ha	40 t/ha	
Control	42.8	46.8	46.3	45.3	45.3
CM	48.7	55.5	74.8	80.1	64.7
VC	52.5	65.9	81.6	82.5	70.6
NC	51.2	57.5	68.5	70.2	61.8
Mean	48.8	56.4	67.8	69.5	
C.D. ($P < 0.05$)					
Treatment mean	2.62				
Rate mean	1.46				
Treatment x rate	5.33				

Data on plant biomass (Table 85) showed that, plants treated with Vermicompost maintained higher biomass over cattle manure and NC. The positive effect was more prominent from 10 t/ha application rate. It appeared that higher biomass production will result in greater sequestration of carbon through photosynthesis.

The rate of evolution of CO_2 from all treatments was found to be maximum (105 to 300 mg) in 1st week of incubation and then the rate declined (Fig.146). The profuse evolution of CO_2 from the soil treated with organic manures on the first week of incubation indicated faster rate of decomposition during the initial period. The gradual decline in the subsequent periods indicated that all the readily decomposable components of the added organic manures have been decomposed during the initial period of incubation. The rate of mineralization followed the order: decomposed NC > CM> VC. The kinetic parameters (Table 86) also differed significantly; the highest decomposition rate constant was observed in NC (9.6% per week) and the lowest in VC (4.9% per week). The half life of mineralization varied from 13.9 weeks in VC to 7.2 weeks in NC.

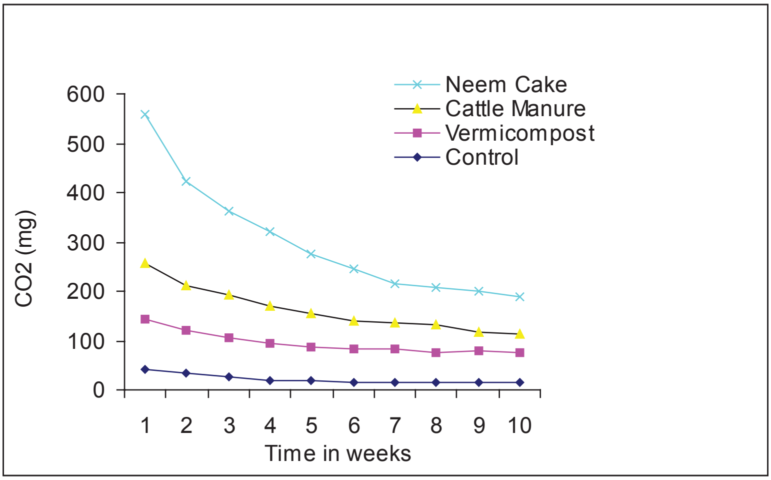


Fig. 146. Release of Carbon dioxide

Table 86. C mineralization potential, rate constant and half life of mineralization in soil treated with different organic manures

Manure	C/N	C- mineralisation potential (mg/100 g soil)	C-mineralisation rate constant K week^{-1}	Half life of C-mineralisation $T_{1/2}$ (week)
VC	18	504	0.049	13.9
CM	28	407	0.057	11.9
NC	10	579	0.096	7.2

The low value of rate constant and higher value of half life of decomposition of VC and CM in soil indicates its superiority to other manures in building up of soil organic carbon. In case of NC the decomposition rate was very high till the end of the 10th weeks of incubation though immobilization occurred in between.

(iii) Field experiment

Analysis of organic matter fractions and microbiological parameters on soil samples collected before imposition of treatments are in progress. Weekly crop record for green leaf (as plucking of the season started only in March 2010 after the imposition of the treatments) is being monitored.

Objective : To raise awareness among tea growers about the climate change scenarios

Following lectures were delivered to raise awareness among growers about the climate change:

1. Bhagat, R.M.2009. Climate change and Water management issues with special focus on drought. Lectures delivered at (a) an awareness seminar organized by the Indian Institute of Plantation Management (IIPM), Bangalore, at Dibrugarh (Assam), (b) Assistant Managers of various tea gardens (Assam and North Bengal) at training programme at Jorhat (c) Climate change awareness lectures in various trainings organized by the Technology Transfer Division of TRA during 2009.

2. Barman T.S. 2009. Impact of climate change on metabolic activities of tea plant and subsequently on yield. Lectures delivered to growers at ASC seminars at Dooars (North Bengal), Terai (North Bengal) Darjeeling (North Bengal) and Upper Assam.

Objective : To analyze and document the concepts of ITK to mitigate impacts of climate change in sustainable tea production

A paper entitled "*Indigenous Technical Knowledge in contemporary relevance to climate change and tea cultivation in Assam*" by R.D. Baruah and R.M. Bhagat is already submitted to the National Co-ordinator of Climate change project.

Objective : To prepare the assessment report of climate change impact, vulnerability and adaptation to climate change in North Eastern India

The draft Assessment report for North Eastern India is already submitted to the National Co-ordinator of Climate change project.

Objective : To validate the CUPPA-tea model in N-E India (*Optional*)

Findings:

We further generated the weather files also and the preliminary results are presented in Fig 147. The results of both simulated and observed valued appear to be quite close. Further work on this aspect with yield simulation from other gardens is going on.

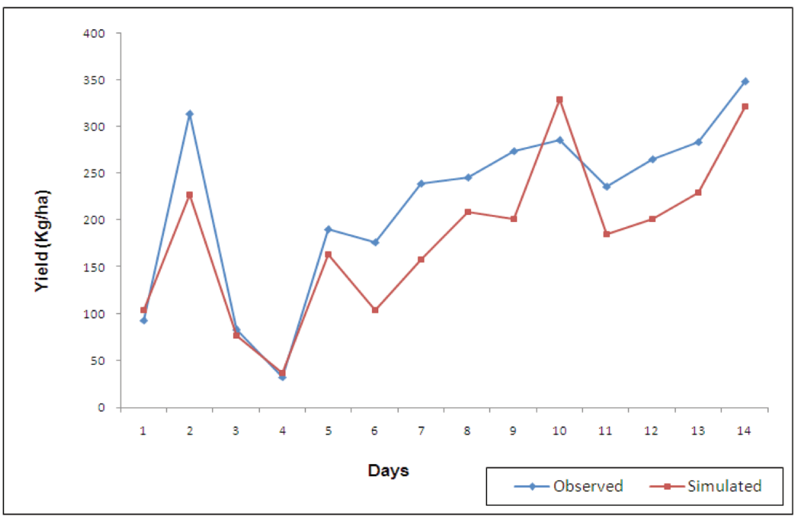


Fig. 147. Observed and simulated results of tea yield for Borbheta T.E. in Assam

ANAND AGRICULTURAL UNIVERSITY
ANAND

Objective : To provide a first estimate of impact of climate change on important crops based on literature review and expert judgment.

Trend analysis of temperature and precipitation at Anand

The linear regression and Theil-Sen approach has been used to analyze the trends in temperature and rainfall using long term data (1959-2009) of Anand. The results of analysis are in Table 87.

Salient findings:

Climatic trend of Anand station

Maximum temperature time series of Anand shows significantly increasing trend for winter (0.03°C/year), monsoon (0.016°C/year), post-monsoon (0.039°C/year) and annual (0.027°C/year).

The minimum temperature also shows increasing trend for winter (0.03°C/year), monsoon (0.016°C/year), post monsoon (0.039°C/year) and annual (0.027°C/year). The rainfall is more stochastic in nature. There is notable difference in linear regression slope and TS slope, but the trend is found non-significant (Table 87).

Table 87. Trend statistics and slopes of maximum temperature for Anand

Parameter	Period/season	Thil-Sen analysis		Regression analysis	
		Slope	Kendall's tau	Slope	R^2
Maximum temp.	Winter	0.030	0.290	0.033	0.120
	Summer	0.017	0.110	0.043	0.110
	Monsoon	0.016c	0.169	0.019	0.070
	Post-monsoon	0.039a	0.310	0.049	0.220
	Annual	0.027a	0.350	0.033	0.240
Minimum temp.	Winter	0.017b	0.220	0.020	0.120
	Summer	0.027a	0.32	0.043	0.11
	Monsoon	0.017a	0.36	0.019	0.07
	Post-monsoon	0.025b	0.22	0.029	0.11
	Annual	0.024a	0.44	0.024	0.41
Rainfall		0.05	1.66	2.14	0.01

a: Significant at 99%, b :Significant at 95%, c: Significant at 90%

Objective : To calibrate and validate InfoCrop model for key food crops (maize, paddy, pearl millet and wheat) in different agro-climatic regions of the state

Calibration and validation of InfoCrop model:

The calibration and validation of InfoCrop model for wheat and maize have been carried out. The experimental details are as under.

(i) Wheat

The data generated in the field experiment were conducted on wheat cv. GW-496 and GW-322 during the year 2005-2007 and 2006 to 2009 respectively under AICRP on Agrometeorology project at College Agronomy Farm, B. A. College of Agriculture have been used to calibrate and validate the InfoCrop model for two cultivars.

Genotype (2):

1. GW-496
2. GW-322

Dates of sowing (3):

1. 1st Nov.
2. 15th Nov.
3. 30th Nov.

Spacing: 22.5 cm between rows

Fertilizer: 120 +60+0 (NPK kg/ha)

Irrigation: At each critical growth stages of the crop

(ii) Maize

The field experiment were conducted on maize cv. Ganga Safed-2 and GM-6 during the year 2004-2006 and 2007 to 2009 at College Agronomy Farm, B. A. College of Agriculture and Main maize Research Station Godhra respectively with recommended package of practices with following treatment.

Genotype (2):

1. Ganga Safed-2
2. Guj. Maize-2

Dates of sowing (2):

1.1st. Nov. (For GS-2)

2. 15th Nov. (For GS-2)

1.1st, 10th and 14th July (For GM-6)

2. 15th, 25th and 29th July (For GM-6)

Spacing: 60x 20cm

Fertilizer: 1.120+60+0 (NPK kg/ha for Hybrid maize GS-2)

2. 60+30+0 (For GM-6 cultivar)

Salient findings:

InfoCrop validation results of wheat:

Biomass and grain yield:

The error percent of biomass yield of wheat (cv. GW-496) as simulated by InfoCrop model (Table 88) was ranged between 7.4 to -8.2 with an average value of 2.7%. In case of cv. GW-322 validation error per cent ranged between 4.0 to 12.4% with an average value of 8%. The error percent of grain yield of wheat (cv. GW-496) as simulated by InfoCrop model was ranged between 7.2 to -2.9 with an average value of ±7.2%. In case of cv. GW-322 validation error per cent ranged between 3.1 to 9.3% with an average value of 9.3. On and average validation of 15th Nov. holds good as compared to rest of the dates of sowing.

Phenology:

The model overestimated the days for anthesis (Table 89) for both the cultivars; however the average percent error for the cultivars was remained around 10%. The error percent for days taken for maturity as simulated by the model for cv. GW-496 and cv. GW-322 showed that higher average error percent were noted for cv. GW-496 as compared to cv. GW-322. The error percent vary according to dates of sowing in both the cultivars.

Leaf area index:

The error percent for LAI for both the cultivars as simulated by the model was underestimated. The average percent error (Table 90) was ±7.8 and ±4.1 for cv. GW-496 and GW-322, respectively.

2. InfoCrop validation results of maize:

Biomass and grain yield:

The biomass yield of GS-2 was overestimated by the model (Table 91) with an average percent error of 9.16. In case of GM-6 model overestimated biomass yield except 1st and 15th July 2007 sowing with an average percent error of ±1.61.

The error percent for grain yield of cv. GS-2 overestimated by the model with an average of 4.81%. Maize cv. GM-6 overestimated the grain yield for all dates of sowing except 1st and 15th July sowing with an average error percent of 1.22.

Phenology:

The percent error for anthesis for GS-2 (Table 92) revealed that model overestimated days taken for anthesis except 1st Nov. 2005 and 1st Nov. 2006 sowing with an average percent error of ±4.69. The results of GM-6 for days taken for anthesis showed that model underestimated the days taken for anthesis with an average percent error of -8.99. The percent error for days taken for maturity for GS-2 showed that model underestimated the days with an average percent error of ±1.89. In case of cv. GM-6 model overestimated the days taken for maturity with an average error percent of 5.66.

Leaf area index

The percent error for LAI for GS-2 (Table 93) showed that model underestimated LAI except 15th Nov. 2004 sowing with an average percent error of ±5.84.In case of GM-6 model underestimated LAI with an average percent error of -13.12.

Table 88. Observed and simulated biomass and grain yield of two cultivars of wheat

Cultivar / Date of sowing	Biomass (kg/ha)			Grain yield (kg/ha)		
	Observed	Simulated	Error %	Observed	Simulated	Error %
GW-496						
D1 (1st Nov.)	8257	7584	-8.2	3744	4023	7.2
D2 (15th Nov.)	8346	9070	8.7	4712	4579	-2.9
D3 (30th Nov.)	8536	9164	7.4	4399	4549	3.2
Avg.	8380	8606	2.7	3744	4023	7.2
GW-322						
D1 (1st Nov.)	6955	7478	7.6	3703	3788	3.1
D2 (15th Nov.)	8333	8678	4.0	4128	4391	6.3
D3 (30th Nov.)	9127	10252	12.4	4549	4980	9.3
Avg.	8138	8802	8.0	4127	4386	9.3

Table 89. Observed and simulated phenology of two cultivars of wheat

Cultivar / Date of sowing	Anthesis			Days taken for maturity		
	Observed	Simulated	Error %	Observed	Simulated	Error %
GW-496						
D1 (1st Nov.)	62	68	9.2	103	101	-1.9
D2 (15th Nov.)	63	69	10.3	101	100	-1.3
D3 (30th Nov.)	62	68	10.5	98	100	2.5
Avg.	62	68	10.5	101	100	2.5
GW-322						
D1 (1st Nov.)	64	68	7.3	97	99	2.8
D2 (15th Nov.)	63	70	10.6	96	98	2.4
D3 (30th Nov.)	64	71	9.9	96	98	2.1
Avg.	64	71	9.9	96	98	2.1

Table 90. Observed and simulated LAI of two cultivars of wheat

Cultivar / Date of sowing	LAI		
	Observed	Simulated	Error %
GW-496			
D1 (1st Nov.)	2.9	2.5	-13.0
D2 (15th Nov.)	2.6	2.5	-5.2
D3 (30th Nov.)	2.9	2.8	-5.2
Avg.	2.8	2.6	-7.8

Cultivar / Date of sowing	LAI		
	Observed	Simulated	Error %
GW-322			
D1 (1st Nov.)	3.1	2.7	-11.4
D2 (15th Nov.)	2.9	2.6	-10.4
D3 (30th Nov.)	3.4	3.2	-4.1
Avg.	3.4	3.2	-4.1

Table 91. Observed and simulated biomass and grain yield of two cultivars of maize

Cultivar / Date of sowing	Biomass (kg/ha)			Grain yield (kg/ha)		
	Obs.	Sim.	Error %	Obs.	Sim.	Error %
Ganga Safed-2						
D1 (1st Nov.)	11345	12173	7.23	3235	3446	6.60
D2 (15th Nov.)	11986	13292	10.89	3356	3448	3.02
Avg.	12486	13630	9.16	3295	3447	4.81
GM-6						
1st July2007	7221	8921	-9.48	2513	2633	4.8
15th July 2007	7162	6482	-10.71	2125	2238	5.34
10th July 2008	7322	6538	6.85	1908	2111	10.64
25th July 2008	7295	7795	10.73	2244	2514	12.04
14th July 2009	7438	8236	4.25	2245	2712	20.8
29th July 2009	7221	7632	5.69	2354	2509	6.61
Avg.	7277	7601	1.22	2232	2453	10.04

Table 92. Observed and simulated phenology of two cultivars of maize

Cultivar / Date of sowing	Anthesis			Days taken for maturity		
	Obs.	Sim.	Error %	Obs.	Sim.	Error %
Ganga Safed-2						
D1 (1st Nov.)	76	76	0.05	120	119	-1.34
D2 (15th Nov.)	75	82	9.33	122	119	-2.44
Avg.	76	79	4.69	121	119	-1.89
GM-6						
1st July 2007	57	50	-12.88	77	80	3.89
15th July 2007	54	51	-5.55	80	83	3.75
10th July 2008	55	51	-7.27	78	82	5.12
25th July 2008	58	52	-10.34	75	82	9.33
14th July 2009	57	51	-10.52	79	82	3.79
29th July 2009	54	50	-7.4	74	80	8.10
Avg.	56	51	-8.99	77	82	5.66

Table 93. Observed and simulated LAI of two cultivars of maize

Cultivar / Date of sowing	LAI		
	Observed	Simulated	Error %
Ganga Safed-2			
D1 (1st Nov.)	4.56	3.99	-12.39
D2 (15th Nov.)	4.73	4.76	0.70
Avg.	4.64	4.38	-5.84
GM-6			
1st July 2007	3.54	3.18	-10.16
15th July 2007	3.66	3.20	-12.99
10th July 2008	3.21	2.84	-12.56
25th July 2008	2.98	2.31	-11.52
14th July 2009	3.20	2.64	-17.50
29th July 2009	2.85	2.45	-14.03
Avg.	3.24	2.77	-13.12

Objective: To simulate the impacts of different scenarios of climate change on crop production

Work carried out- methodology used

The PRECIS projection output of scenario A2, B2 and baseline were considered for projection of weather for 2071 to 2100. As the baseline (1961-1990) data generated by PRECIS showed marked differences with actual (1961-90) data recorded at Anand station. So, the projected data were calculated considering actual data (1961-90) of Anand station. The difference between PRECIS baseline and A2 scenario was added to actual data of 1961-90 to get weather data for 2071-2100. Two approaches were adopted (i) day to day actual data of 1961-90 as baseline and (ii) daily normal (1961-90) as baseline. The crop model InfoCrop was used to study the crop response with the weather data generated using first approach i.e., day to day sum of actual weather data of 1961-90 and changes calculated using PRECIS baseline and A2 scenario projection data.

The grid wise data of maximum, minimum temperature and rainfall have been separated for different grid points of Middle Gujarat Agro-climatic zone. Subsequently based on monthly mean daily data were generated and prepared data of A2 scenario for above mentioned parameters. Summary figures have been prepared for rainfall, Tmax and Tmin. The InfoCrop model was run for individual year using A2 scenario daily weather data. The PRECIS generated rainfall, Tmax and Tmin for Base line and their comparison with the years of 2071, 2075, 2080, 2085, 2090, 2095 and 2100 are depicted in Fig. 148 to 150. PRECIS generated weather condition for various stations of Middle Gujarat Agro-climatic zone is presented in Table 94.

The weather parameters calculated using normal of base period 1961-90 and PRECIS projected changes i.e., A2 scenario PRECIS minus generated data of base period of Anand station of Middle Gujarat Agro-climatic region showed that Khandha station will receive 88% higher and Dharmaj station will receive 29% lower rainfall in the year 2095 and 2100 respectively as compared to their respective base line. Amongst all the stations under study Dabhoi will receive lowest rainfall and Khandha will receive highest rainfall. Nearly 8.15^{0}C and 2.38^{0}C positive temperature changes will prevail at Dhabhoi during 2100 and Dharmaj during 2080 years respectively as compared to their respective base line. Dabhoi station will remain warmer as compared to other station. Similarly at Dharmaj station minimum temperature change will remain to the tune of 6.23^{0}C and at Khandha station it will remain 1.93^{0}C during 2100 and 2080 years, respectively. Khandha station will remain cooler as compared to other station.

Wheat yield trends

The base line wheat yields of two wheat cultivars viz., GW-496 and GW-322 and their yield performance in different dates of sowing are presented in Table 95. Results showed that grain yield of wheat of both the cultivars found decreasing as compared to their base line yield. Highest yield reduction was noticed in D1 (1st Nov. sowing in both the cultivars. Cultivar GW-322 performed better in early, late and very late sowing, whereas GW-496 performed better only up to late sowing. This results shows that cv. GW-322 might be heat resistant, while GW-496 be heat sensitive cultivar.

Trends of wheat yield, yield attributing characters and phenology:

The variations in wheat yield, biomass, leaf area index and days to anthesis of both the cultivars showed that highest wheat yield of GW-496 was noticed during 2087 (4915 kg/ha) in D3 sowing, whereas lowest yield was found (352 kg/ha) in D1 sowing during 2078. Overall highest yield was observed in D3 and lowest in D1 sowing. The highest total dry matter was observed in D3 sowing (9878 kg/ha) during the year 2088 whereas lowest (1218 kg/ha) was noticed in D1 sowing in the year 2076. Overall D3 observed higher total biomass yield. Highest LAI (3.96) was observed in D3 sowing during 2087 whereas lowest LAI (0.42) was noticed in D1 sowing in the year 2086. Highest anthesis days (85) were observed in D2 sowing during 2095 whereas lowest (56) was recorded in D3 sowing in 2089. Higher days of anthesis were recorded in D1 sowing. Under cv. GW-322 highest yield (5248 kg/ha) was observed form D4 sowing in the year 2077 whereas lowest (352 kg/ha) was observed from D4 sowing in the year 2100. Overall higher yield was noticed from D3 sowing as compared to rest of the sowing. Highest dry biomass (11125 kg/ha) was observed in D3 sowing during 2087 whereas lowest (1023 kg/ha) was observed from D3 sowing during the year 2098. Overall higher biomass yield was seen from D3 sowing. Overall higher LAI was observed in D3 sowing as compared to rest of the sowing. Similarly higher days to anthesis were recorded in D1 sowing.

Overall highest yield, biomass and LAI were recorded by both the cultivars under D3 sowing.

Salient findings:

1. Highest yield reduction was noticed in D1 (1st Nov. sowing in both the cultivars of wheat. Cultivar GW-322 performed better in early, late and very late sowing, whereas GW-496 performed better only up to late sowing. This results shows that cv. GW-322 might be heat resistant, while GW-496 be heat sensitive cultivar.
2. Khandha station of Vadodara district will remain cooler as compared to other station.
3. Overall highest grain yield, biomass and LAI will be recorded by cv. GW-496 and cv. GW-322 of wheat crop under D3 (30th Nov.) sowing.

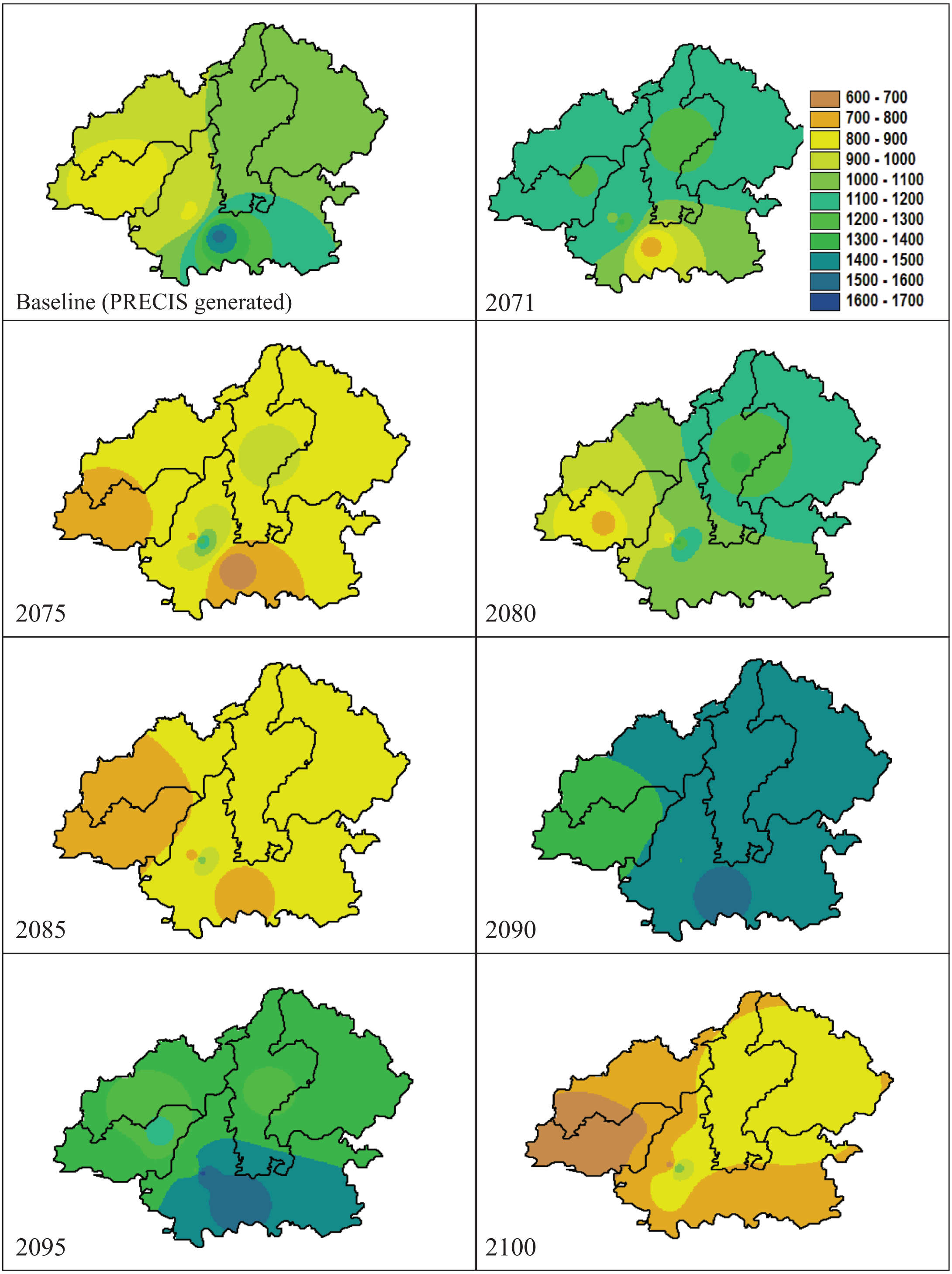


Fig. 148. PRECIS generated rainfall for Middle Gujarat Agro-climatic zone (Projection data using normal of base period (1961-90) and PRECIS projected change)

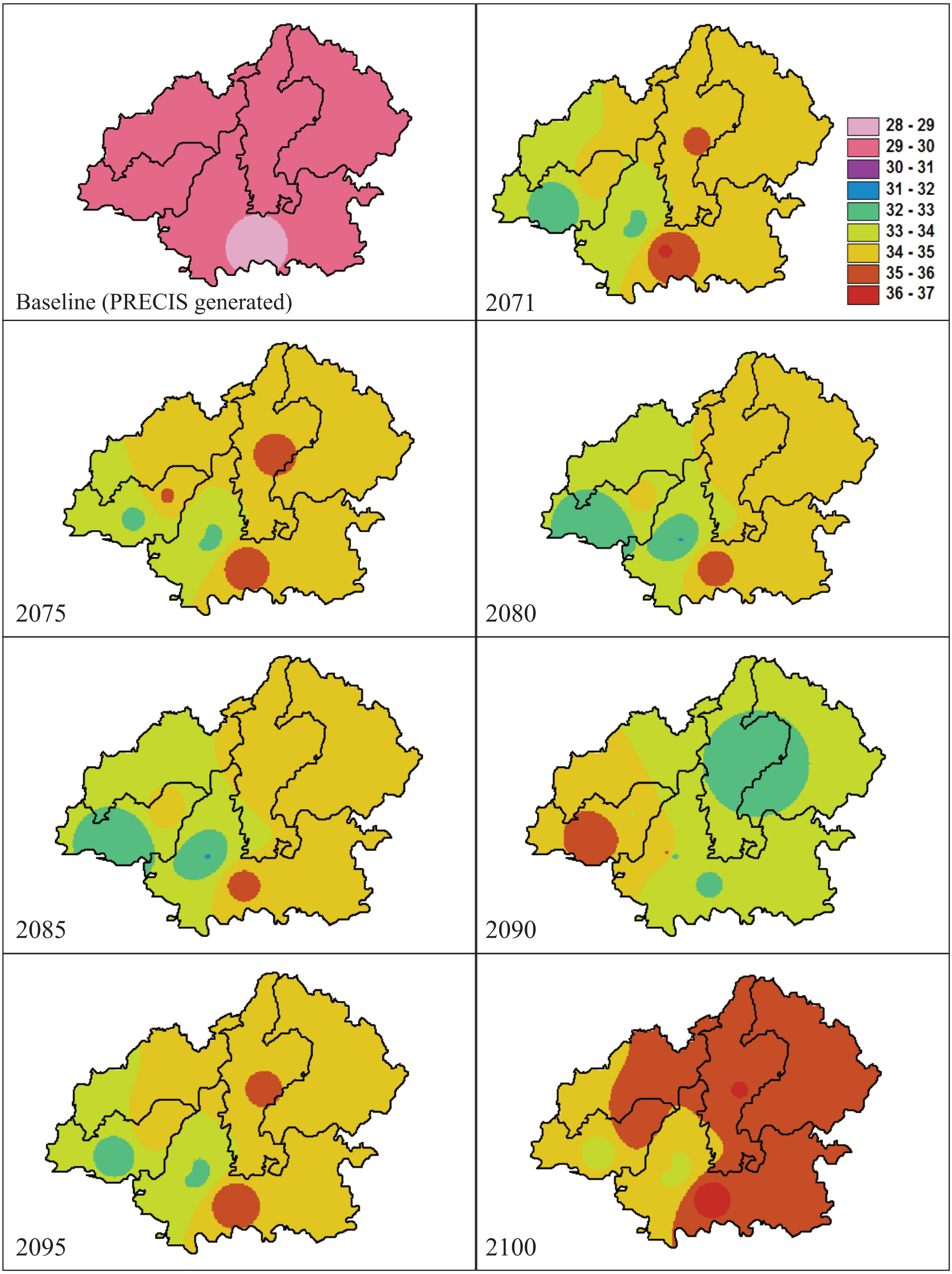


Fig. 149. PRECIS generated maximum temperature for Middle Gujarat Agro-climatic zone (Projection data using normal of base period (1961-90) and PRECIS projected change)

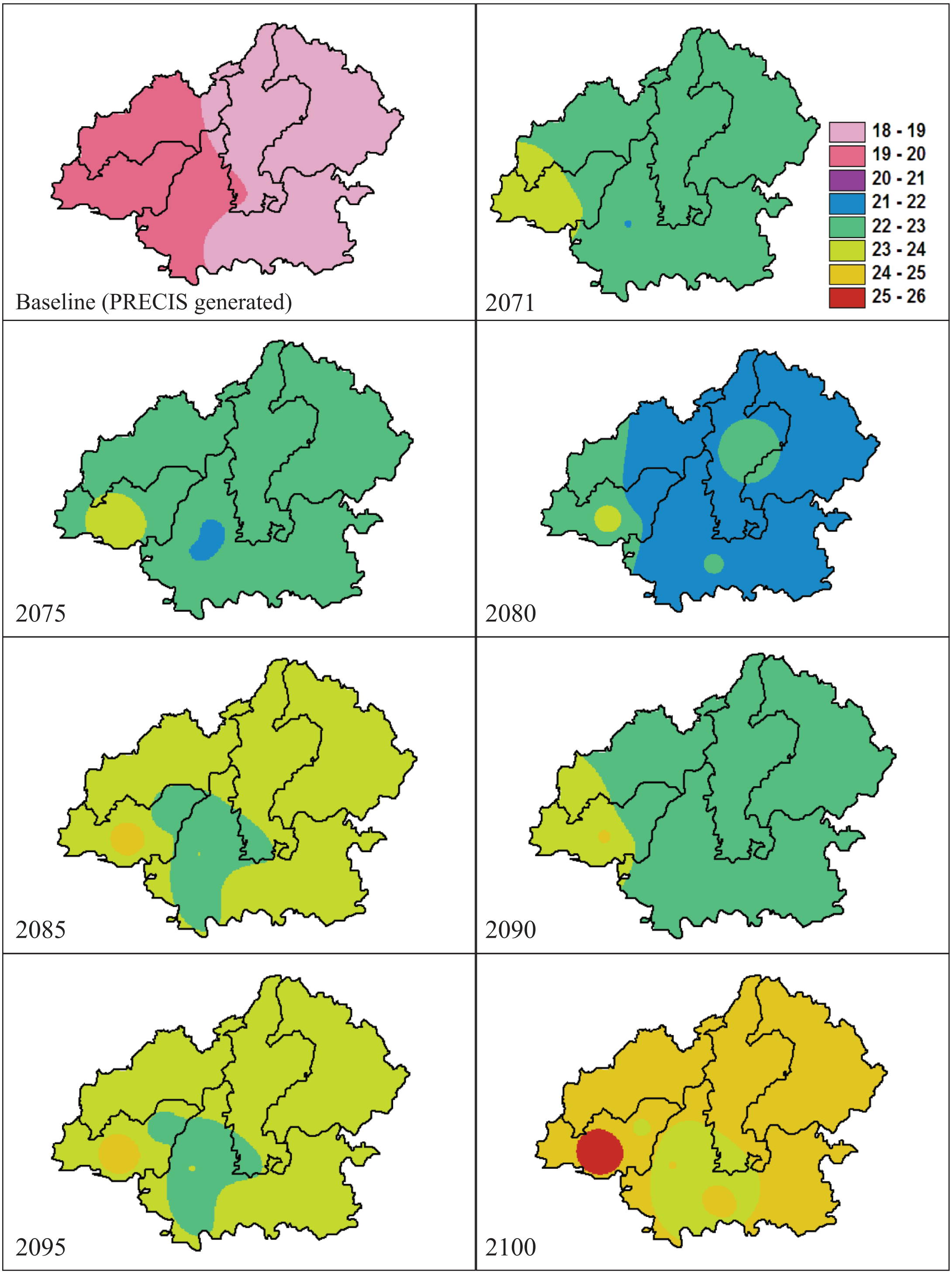


Fig. 150. PRECIS generated minimum temperature for Middle Gujarat Agro-climatic zone (Projection data using normal of base period (1961-90) and PRECIS projected change)

Table 94. PRECIS generated weather condition for various stations of Middle Gujarat Agro-climatic zone

	Rainfall (mm)	Tmax. (^{0}C)	Tmin. (^{0}C)	Change in parameters		
				RF %	Tmax. (^{0}C)	Tmin. (^{0}C)
Anand (22° 32’N 72°59’E)						
Base Line	919.2	29.8	19.1	--	--	--
2071	1278.6	34.8	22.5	39.1	5.0	3.4
2075	852.6	35.2	22.2	-7.2	5.4	3.1
2080	1048.3	34.5	21.6	14.0	4.7	2.6
2085	772.3	34.7	22.8	-16.0	4.9	3.8
2090	1436.0	34.1	22.5	56.2	4.2	3.4
2095	1192.1	35.0	22.9	29.7	5.2	3.8
2100	736.9	36.0	24.0	-19.8	6.2	4.9
Godhra (22° 45’N 73°36’E)						
Base Line	1096.7	29.4	18.8	--	--	--
2071	1294.1	35.2	23.0	18.0	5.7	4.2
2075	970.2	35.3	22.6	-11.5	5.8	3.8
2080	1362.9	34.8	22.1	24.3	5.4	3.3
2085	947.4	34.9	23.4	-13.6	5.5	4.5
2090	1517.9	32.3	22.9	38.4	2.9	4.1
2095	1327.3	35.2	23.4	21.0	5.8	4.5
2100	904.8	36.1	24.3	-17.5	6.7	5.5
Dabhoi (23° 25’N 72°50’E)						
Base Line	1581.3	28.6	18.9	--	--	--
2071	792.5	36.2	22.8	-49.9	7.6	4.0
2075	660.2	35.9	22.5	-58.2	7.3	3.6
2080	1082.2	35.9	22.1	-31.6	7.3	3.2
2085	793.9	35.6	23.2	-49.8	7.1	4.3
2090	1614.0	32.9	22.4	2.1	4.3	3.5
2095	1623.2	36.0	23.2	2.6	7.4	4.3
2100	791.1	36.7	24.1	-50.0	8.2	5.2
Dharmaj (22° 24’N 72°47’E)						
Base Line	892.8	29.8	19.5	--	--	--
2071	1200.3	32.4	24.0	34.4	2.6	4.6
2075	774.5	32.8	23.7	-13.3	3.1	4.3
2080	811.3	32.2	23.4	-9.1	2.4	4.0

	Rainfall (mm)	Tmax. (^{0}C)	Tmin. (^{0}C)	Change in parameters		
				RF %	Tmax. (^{0}C)	Tmin. (^{0}C)
2085	816.5	32.2	24.4	-8.5	2.4	5.0
2090	1405.1	35.8	24.1	57.4	6.0	4.6
2095	1385.8	32.6	24.5	55.2	2.8	5.1
2100	635.7	33.7	25.6	-28.8	3.9	6.2
Khandha (22° 30'N 73°58'E)						
Base Line	892.2	29.5	19.1	--	--	--
2071	1394.8	32.3	21.9	56.3	2.8	2.8
2075	1321.7	32.2	21.5	48.1	2.7	2.4
2080	1417.6	32.0	21.1	58.9	2.4	1.9
2085	1109.0	31.9	22.3	24.3	2.4	3.2
2090	1450.4	32.8	22.5	62.6	3.3	3.4
2095	1677.1	32.3	22.3	88.0	2.7	3.1
2100	1144.4	33.1	23.2	28.3	3.6	4.1
Vadodara (22° 30'N 73°14'E)						
Base Line	980.1	29.7	19.3	--	--	--
2071	1080.7	33.3	22.7	10.3	3.6	3.5
2075	756.8	33.5	22.4	-22.8	3.8	3.1
2080	832.6	33.0	21.9	-15.0	3.3	2.7
2085	780.8	33.1	23.1	-20.3	3.3	3.8
2090	1472.0	35.2	22.8	50.2	5.5	3.5
2095	1338.5	33.4	23.1	36.6	3.7	3.9
2100	692.9	34.4	24.2	-29.3	4.6	4.9

Table 95. PRECIS generated weather condition and wheat yield of Anand station of Middle Gujarat Agro-climatic zone

Year	Rainfall (mm)	Tmax. (^{0}C)	Tmin. (^{0}C)	Change in parameters			Wheat cv. GW-496 yield (kg/ha)				Wheat cv. GW-322 yield (kg/ha)			
				RF %	Tmax. (^{0}C)	Tmin. (^{0}C)	D1	D2	D3	D4	D1	D2	D3	D4
Base line	919.2	29.8	19.1	--	--	--	3892	4520	4641	4355	3608	4322	4728	4513
2071	1339.2	38.2	24.0	46	8.4	4.9	483	707	1988	3154	998	537	1789	2559
2072	1102.8	36.7	22.3	20	6.9	3.2	981	1512	1879	792	1456	907	2235	2126
2073	1033.8	38.4	24.5	12	8.6	5.4	1163	1213	1729	649	803	1219	1715	378
2074	987.5	38.5	23.2	7	8.7	4.1	1216	1487	850	1679	1222	619	849	502
2075	811.5	39.1	23.7	-12	9.3	4.6	489	1570	831	722	933	383	616	439
2076	786.2	39.3	23.9	-14	9.5	4.8	1282	1213	663	588	833	1873	2023	1756
2077	1650.7	35.9	23.5	80	6.1	4.4	1804	2294	3832	2875	1631	2006	4226	5248
2078	1063.1	36.1	22.4	16	6.3	3.3	352	2006	2936	3199	600	756	2744	2806
2079	1457.1	36.7	24.1	59	6.9	5.0	441	1196	2460	3423	638	1248	2316	2292
2080	1775.6	36.1	23.0	93	6.3	3.9	512	1982	2345	2144	1023	1365	2895	2415
2081	1059.2	36	24.6	15	6.2	5.5	650	2078	2833	2866	454	1735	2475	2382
2082	753.2	36.8	24.5	-18	7	5.4	656	1239	2563	2482	501	1120	1800	1890
2083	1647.2	37.6	23.2	79	7.8	4.1	3261	4481	1972	1506	3381	4359	2688	3215
2084	1140.3	38.7	23.9	24	8.9	4.8	3412	3212	2015	1815	932	2015	3215	2415
2085	1666.1	36.1	24.0	81	6.3	4.9	678	951	661	1368	517	1066	1059	1202
2086	2416.1	36.5	24.0	163	6.7	4.9	697	1494	1859	1578	533	1084	1756	2246
2087	1930.5	35.8	23.4	110	6	4.3	440	2687	4915	1686	432	2421	4304	4025
2088	1203.8	37.7	24.4	31	7.9	5.3	578	2712	3812	1516	3012	2146	3842	3125
2089	1279.1	37.8	25.1	39	8	6.0	1497	2370	3565	3153	1433	2402	3317	3526
2090	1389.5	37	23.9	51	7.2	4.8	1116	2100	1770	1305	938	1538	1380	855
2091	1427.2	39.2	24.8	55	9.4	5.7	1259	1417	582	1562	1196	1199	1484	1872
2092	1116.7	38.5	26.2	21	8.7	7.1	1349	1528	685	2258	1356	1456	2513	1994

Year	Rainfall (mm)	Tmax. (^{0}C)	Tmin. (^{0}C)	Change in parameters			Wheat cv. GW-496 yield (kg/ha)				Wheat cv. GW-322 yield (kg/ha)			
				RF %	Tmax. (^{0}C)	Tmin. (^{0}C)	D1	D2	D3	D4	D1	D2	D3	D4
2093	1103.1	38.5	25.0	20	8.7	5.9	1865	653	2676	2829	881	397	2039	2997
2094	1575.8	37.8	24.2	71	8	5.1	565	897	434	1161	706	503	1456	1236
2095	1040.3	38.7	24.5	13	8.9	5.4	436	1226	568	511	822	1236	1331	321
2096	625.7	38.4	25.4	-32	8.6	6.3	456	389	678	586	2699	1598	3152	2654
2097	1557.5	39.3	25.7	69	9.5	6.6	3154	2147	1996	1616	3352	3022	1260	1214
2098	1757.9	38.1	24.8	91	8.3	5.7	2044	2583	2937	2512	3841	4423	4012	3698
2099	1376.3	37.3	24.3	50	7.5	5.2	1222	1244	1685	1484	1114	1315	745	353
2100	1286.5	38.5	26.0	40	8.7	6.9	1222	1244	1685	1484	1114	1315	745	353
Mean	1312.0	37.6	24.2	--	--	--	1176.0	1727.7	1980.1	1816.8	1311.7	1575.4	2199.4	2069.8
SD	383.3	1.8	1.3	--	--	--	953.8	961.2	1199.5	960.9	1004.2	1076.8	1123.9	1270.9
CV %	29.2	4.7	5.3	--	--	--	81.1	55.6	60.6	52.9	76.6	68.3	51.1	61.4

Where: D1: Very early sowing: 1st Nov. D2: Early sowing: 15th Nov. D3: late sowing: 30th Nov. D4: Very late sowing: 10th Dec.

Objective : To quantify the suitability of various agronomic measures for adaptation to climate change

The InfoCrop model was run for various agronomic measures for adaptation to climate change for two wheat cultivars for optimizing the yield. In this context both the cultivars have been simulated under different shifting of sowing windows such as D1: Very early sowing: 1st Nov., D2: Early sowing: 15th Nov., D3: late sowing: 30th Nov. and D4: Very late sowing: 10th Dec. Yields of both the cultivars have been compared under different sowing windows. Under different sowing windows the yield, yield attributing characters and phenology of both the cultivars have been studied.

Salient findings

The wheat Cv. GW-322 performed better in terms of grain yield under early, late and very late sowing, whereas GW-496 performed better only up to late sowing.

Assessment of adaptation options

The shifting of sowing windows and yield levels in two wheat cultivars are depicted in Fig.151. Results showed that GW-322 performed better in early, late and very late sowing, whereas GW-496 performed better only up to late sowing.

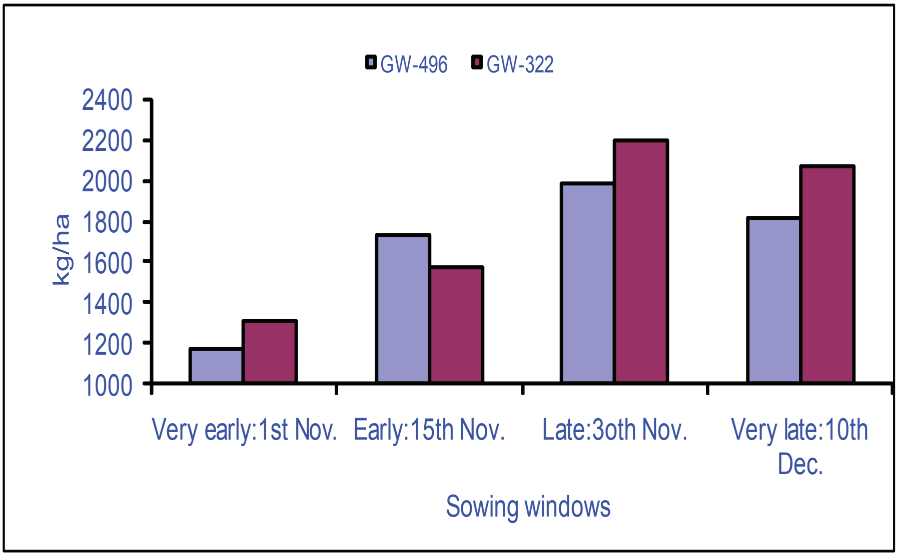


Fig.151. Shifting of sowing window and yield levels in two wheat cultivars

DIRECTORATE OF SOYBEAN RESEARCH
INDORE

Objective : Calibration and validation of InfoCrop for Soybean

To calibrate and validate the InfoCrop model for soybean crop, large number of data sets was collected from the experiments conducted at National Research Centre for Soybean, Annual reports of All India Coordinated Research Project on Soybean (AICRPS) and published literature. These data sets were from the field experiments with soybean cultivar JS 335 (which is the most popular cultivar and occupies maximum area under soybean in India) conducted over a period of 1988 to 2003 in diverse Indian locations ranging in latitude, longitude and elevation. The locations provided a wide range of environment for the testing and validation of model with the observed changes in soils, weather parameters and agronomic practices. The phenology, dry matter and yield at harvest of soybean cultivar JS 335 was validated with 27 data sets available in AICRPS reports for the locations namely Indore, Parbhani, Amravati, Pune, Jabalpur, Dharwad and Bangalore. Similarly, for validation of growth parameters, data of field experiments conducted at Indore, Bhopal and Hyderabad were used (Fig.153). To evaluate the model performance and accuracy in prediction, statistical indicators of root mean square error (RMSE) and Willmott index of agreement (*d* value) were computed from the observed and simulated variables (leaf area index, total above ground biomass, seed biomass, days to flowering and days to maturity).

Evaluation of the InfoCrop model for soybean with large number of experimental data that included 27 experimental data sets of different years and management practices conducted at 7 diverse locations under AICRPS indicated that the model predicted phenology (days to flowering and days to maturity) reasonably well (Fig.152). The average predicted days to flowering and days to maturity in these experiments were 38.7 and 100 days as against observed values of 38.5 and 99 days, respectively. The values for RMSE for days to flowering and days to maturity were 1.8 and 4.9 days, respectively while *d* values for both was 0.81 indicating a good agreement between the simulated and observed values. Similarly, the grain yield at harvest was also predicted reasonably well. The average predicted yield was 2225 kg/ha as compared to the observed value of 2321 kg/ha. The RMSE and the *d* value for grain yield were 506.7 kg/ha and 0.86, indicating a good agreement between observed and predicted grain yield of soybean.

The evaluation of model for crop growth in terms of leaf area index, total biomass and seed weight at different durations observed at three diverse locations indicated that the model also predicted the growth characteristics reasonably well. The observed and simulated leaf area index, crop biomass and grain weight at three locations are presented in Fig 153. The RMSE and *d* values for LAI ranged from 0.48 to 0.96 and 0.73 to 0.93, for crop biomass 406 to 929 kg/ha and 0.93 to 0.99, and for grain weight from 391.3 to 716 kg/ha and 0.87 to 0.94, respectively. The low RMSE values and high *d* values indicated a close agreement between the simulated and observed growth parameters.

The evaluation of model for phenology and growth and yield under diverse environmental conditions clearly indicated that the InfoCrop model can be used for simulation of soybean growth and yield under diverse climatic conditions, agronomic practices and climate change scenarios.

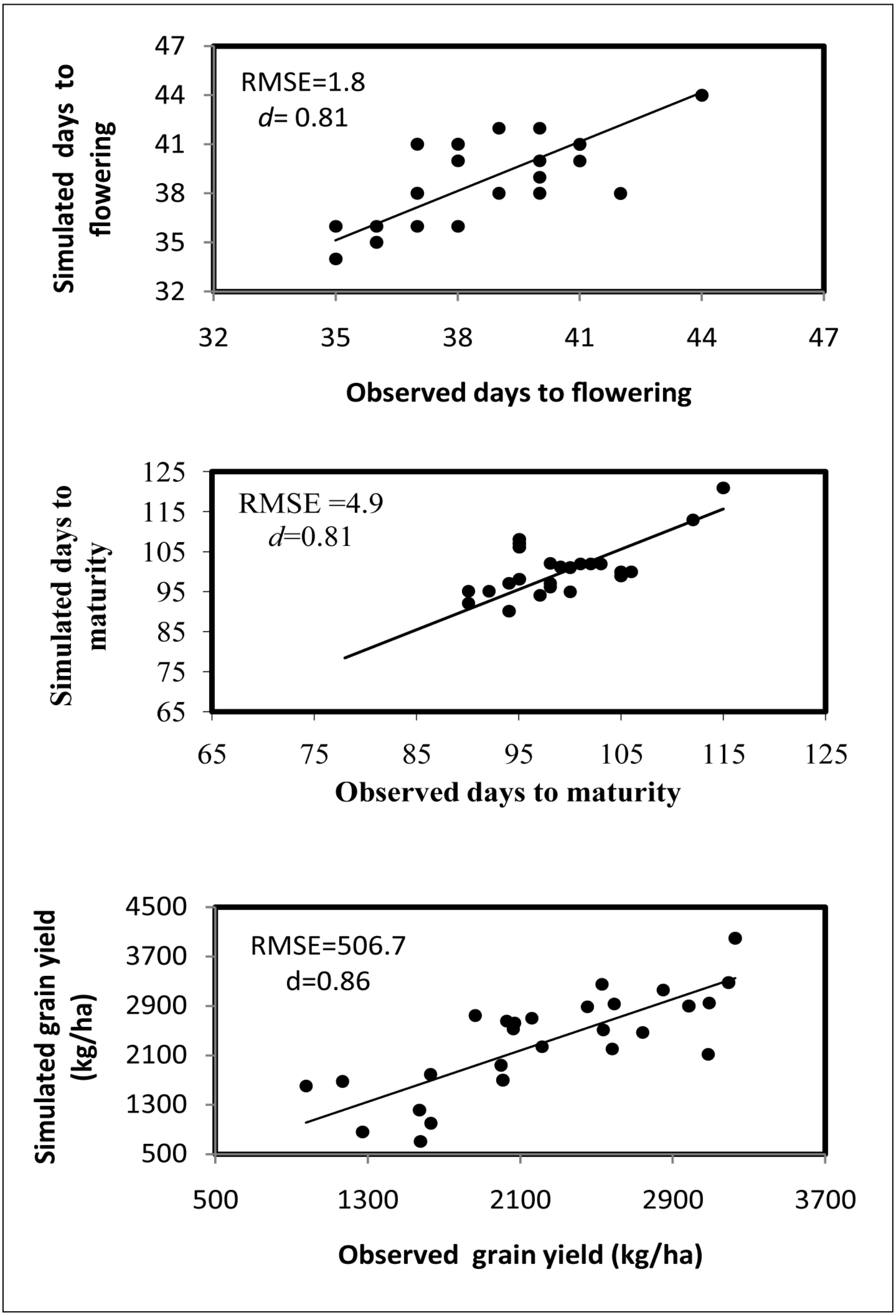


Fig.152. Comparison of simulated and measured (a) days to flowering and (b) days to maturity and (c) grain yield at harvest of soybean cultivar JS 335

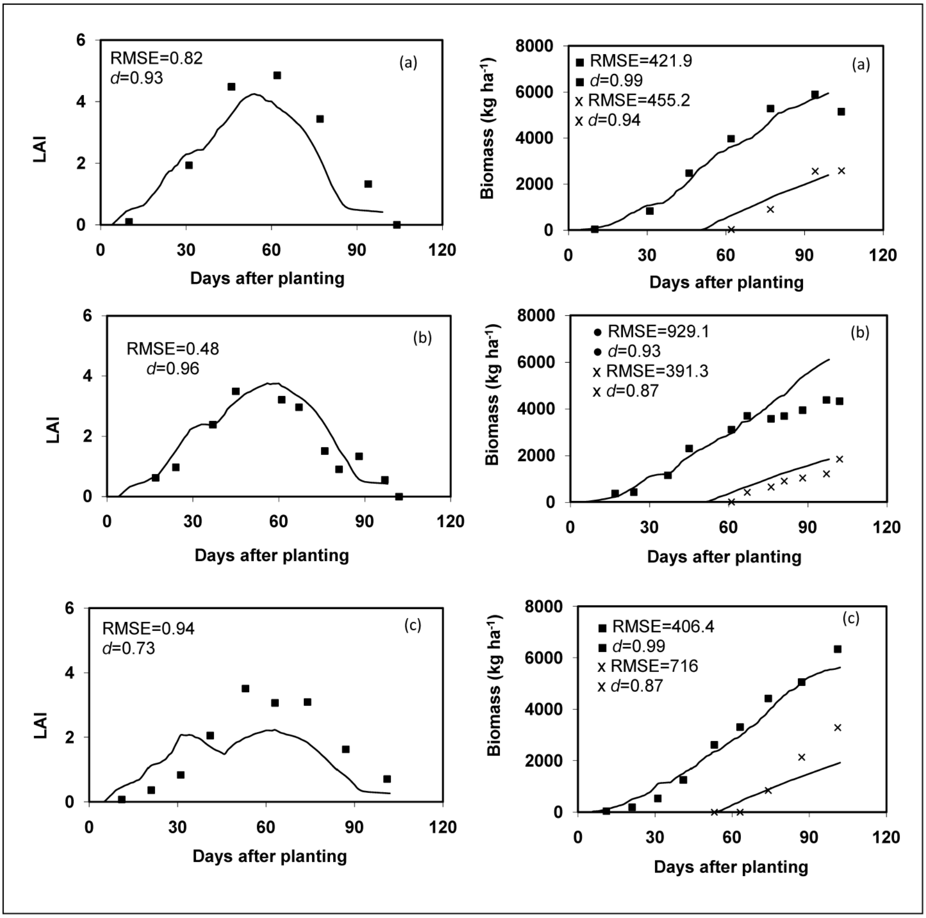


Fig.153. Comparison of simulated (lines) and observed (data points) values of leaf area index (LAI), above ground biomass (■) and seed weight (×) of soybean cultivar JS 335 at (a) Indore (b) Bhopal and (c) Hyderabad

Objective : Calibration and validation of InfoCrop for groundnut

For calibration and validation of InfoCrop model for groundnut, a large number of experimental data sets were collected from published work. The process followed was similar to describe for InfoCrop model for soybean. For evaluation of model, 21 data sets of field experiments with groundnut variety Robut 33-1 conducted from 1987 to 1992 at four locations (Anand, Patancheru, Anantpur and Coimbatore) ranging in latitude, longitude and elevation were used. These locations provided a wide range of environments for testing of the model as they deferred in soils, rainfall, and other elements of climate. The evaluation of phenology indicated that the model was able to predict days to flowering and days to maturity reasonably well (Fig.154). Average predicted days to flowering and days to maturity were 31.1 and 119.2 days as compared to the observed values of 31.3 and 118 days, respectively. The RMSE and *d* value for days to flowering and days to maturity were 6.33 day and 0.73, and 8.72 days and 0.84, respectively indicating a close agreement between observed and simulated phenology of groundnut. Similarly, the average predicted total dry matter and pod yield at harvest were 6.12 and

2.46 t/ha as compare to observed values of 5.7 and 2.47 t/ha, respectively. The low RMSE (1.88 and 0.66 t/ha) and high *d* values (0.81 and 0.88) for total dry matter and grain yield at harvest, respectively indicated a close agreement between the observed and simulated values.

The evaluation of model for crop growth in terms of total biomass and seed weight at different durations observed at three diverse locations (Anantpur, Coimbatore and Anand) indicated that the model also predicted the growth characteristics reasonably well. The observed and simulated total dry matter and pod weight under irrigated and rainfed conditions (Anantpur and Coimbatore) and for irrigated conditions at Anand are presented in Fig 155. The low RMSE and high *d* values for dry matter and for pod weight indicated a close agreement between the simulated and observed growth parameters.

The evaluation of model for phenology, growth and yield under diverse environmental conditions clearly indicated that the InfoCrop model can be used for simulation of groundnut growth and yield under diverse climatic conditions, agronomic practices and climate change scenarios.

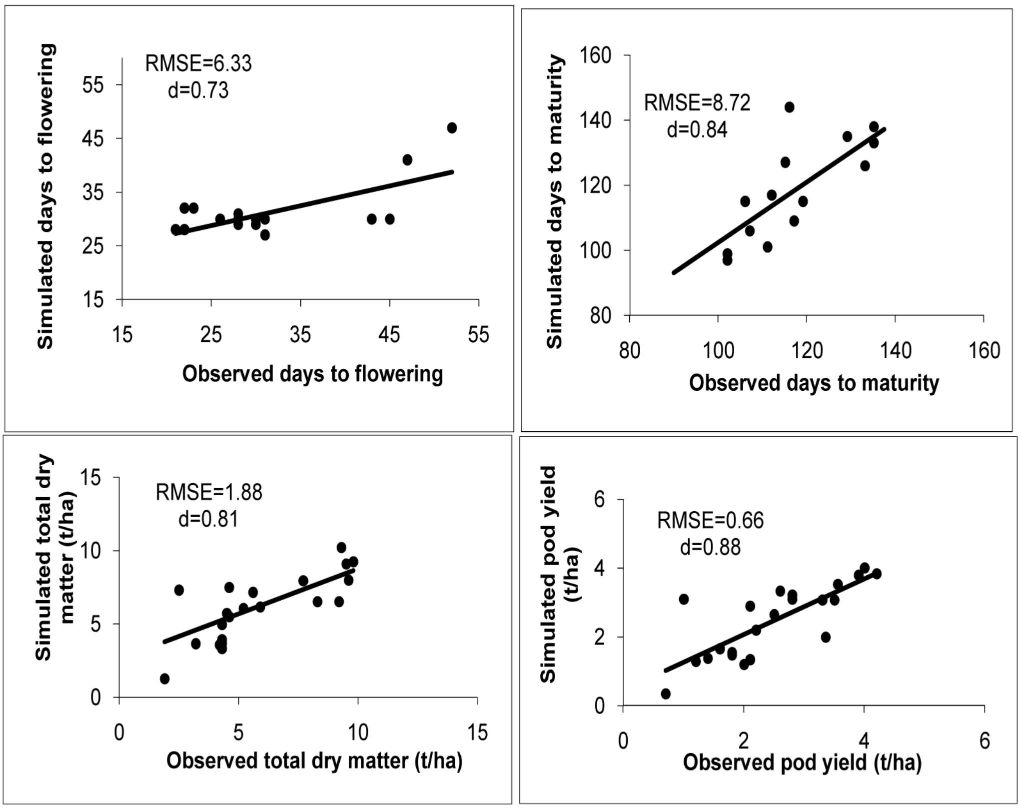


Fig.154. Comparison of simulated and measured days to flowering, total dry matter at harvest and pod yield at harvest of groundnut cultivar Robut 33-1

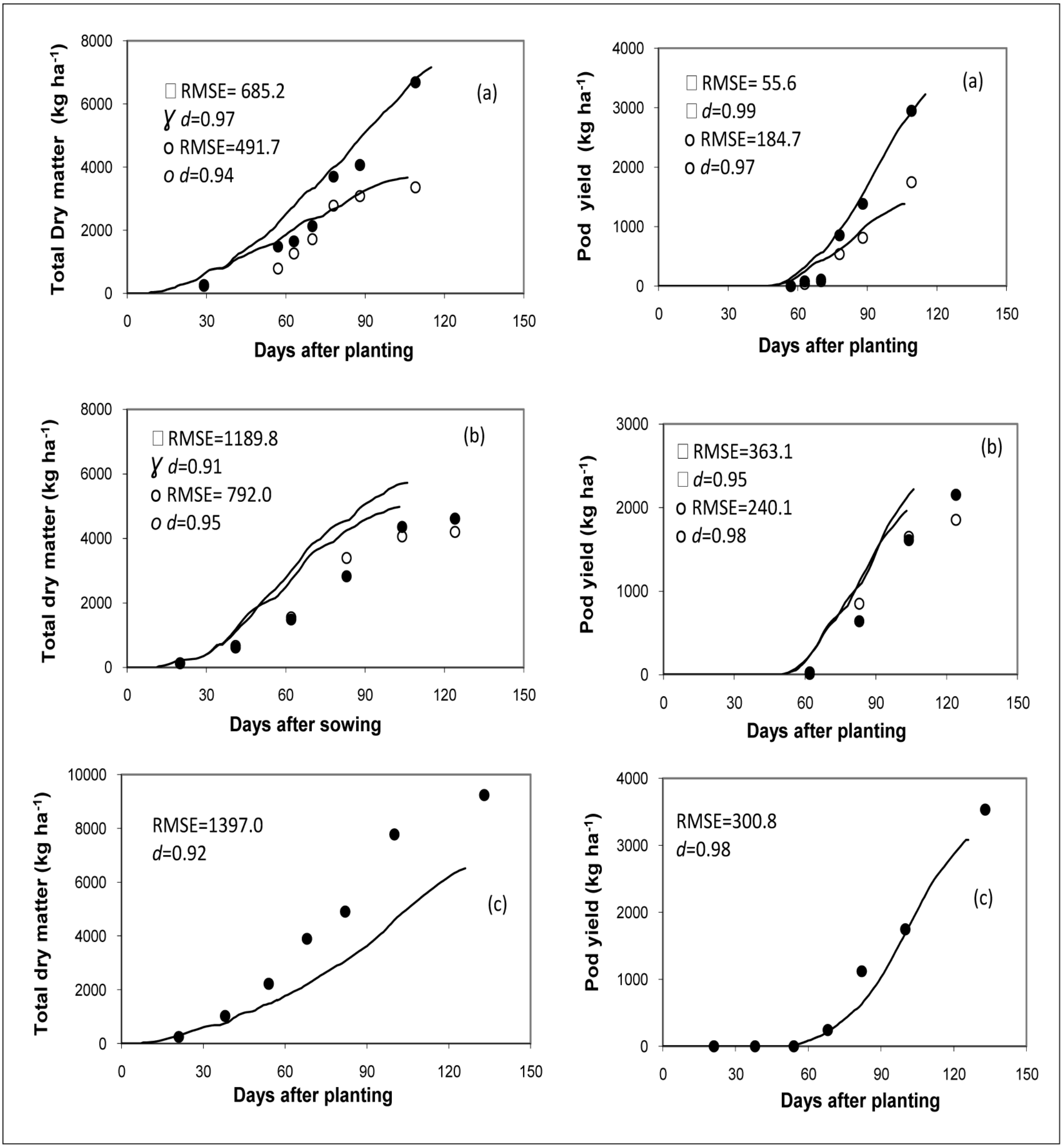


Fig.155. Comparison of simulated (lines) and observed (data points) values above ground total dry matter and pod weight of irrigated (●) and rainfed (o) groundnut cultivar 33-1 at (a) Anantpur (b) Coimbatore and (c) Anand

Objective: Simulation of rainfed yields of soybean and groundnut under current and future climate scenarios

The calibrated and validated InfoCrop models were used for the assessment of climate change impact on the productivity of soybean and groundnut. Simulations of growth and yield for the current (baseline, 1961-1990), and future climate scenarios (provided by IITM, Pune under NATCOM) namely, by middle of this century A1B (2021-2050) and by the end of this century (2071-2100) A1B, B2 and A2 scenarios with projected change in temperature, CO_2, and rainfall were carried out using above models. The atmospheric CO_2 values considered for the simulations were based on the projected values of the Bern CC model for different climate scenarios (IPCC 2001). The average values of atmospheric CO_2 concentration used were 467, 654, 567 and 723 ppm for A1B 2021-2050, A1B 2071-2100, B2 2071-2100 and A2 2071-2100 scenarios, respectively.

Analysis of crop simulations results indicated a significant increase in crop season mean air temperature as compared to the current (baseline) temperatures. The increase in mean air temperature ranged from 1.8 to 2.5 by middle of the century in A1B and 3.0 to 3.6, 4.3 to 5.6, and 4.0 to 5.1 ^{0}C by the end of the century in B2, A1B and A2 scenarios, respectively (Fig.156). Similarly, increase in rainfall to the tune of 16, 10, 25 and 15%, respectively was observed for soybean and groundnut for the same scenarios. However, a large spatial variability in the quantum of change in temperature and rainfall across the selected location in major crop growing regions of soybean and groundnut were observed.

The average simulated rainfed yields under current (baseline) scenario were 2144 and 2473 kg/ha for soybean and groundnut, respectively (Fig.157 & 158). These yields are more than double of the national average yields of these crops indicating that even under current climatic conditions, the existing potential of these crops are not being harnessed by the average farmers. The simulation results indicate a positive impact of future climate (combined change in temperature, rainfall and CO_2 levels) on the productivity of the soybean and groundnut crops. As compared to current yields of soybean, 10, 8, 13 and 12% increase in yield was observed by the middle of this century in A1B and by the end of the century in A1B, B2 and A2 scenarios, respectively. In case of groundnut, except for the end of century climate scenario of A1B, which showed a decline of 5% in yield, rest of the scenarios showed 4-7% increase in rainfed yields as compared to the current yield. However, there was a large spatial variability for magnitude of change in the productivity due to future climate scenarios across major crop growing regions of India. Across the locations, the rainfed yields of soybean and groundnut showed significant positive association with crop season rainfall while association with temperature was poor/non-significant, which indicated that under rainfed conditions, the availability of water will remain a major limiting factor for the yields realized by the farmers.

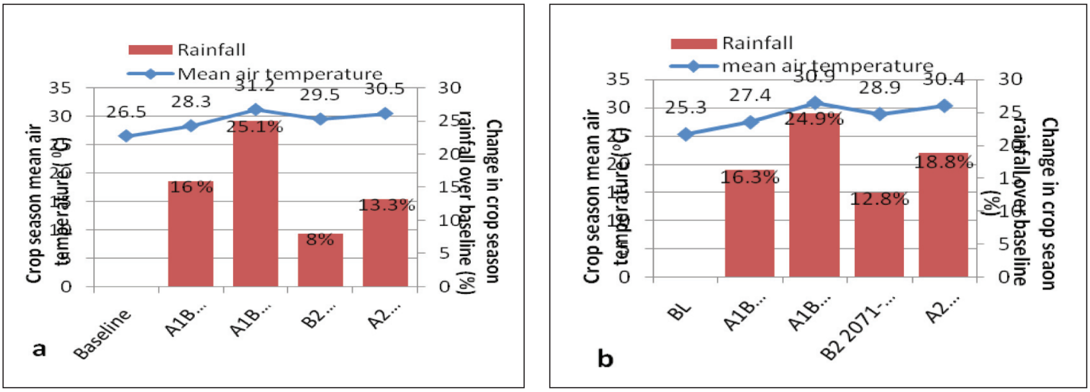


Fig.156. Crop season average mean surface air temperatures under baseline and future climate scenarios and, average percent change in crops season rainfall under future climate scenarios as compared to baseline of selected locations across (a) major soybean growing and (b) groundnut growing regions of India

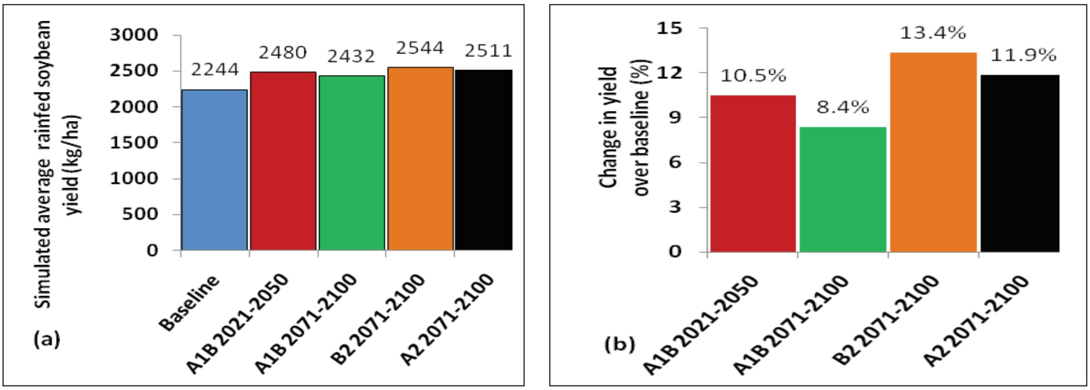


Fig.157. (a) Average simulated rainfed soybean yields under current (baseline) and future climate scenarios and, (b) Projected average change in simulated rainfed soybean yields under future climate scenarios as compared to baseline in major crop growing regions of India

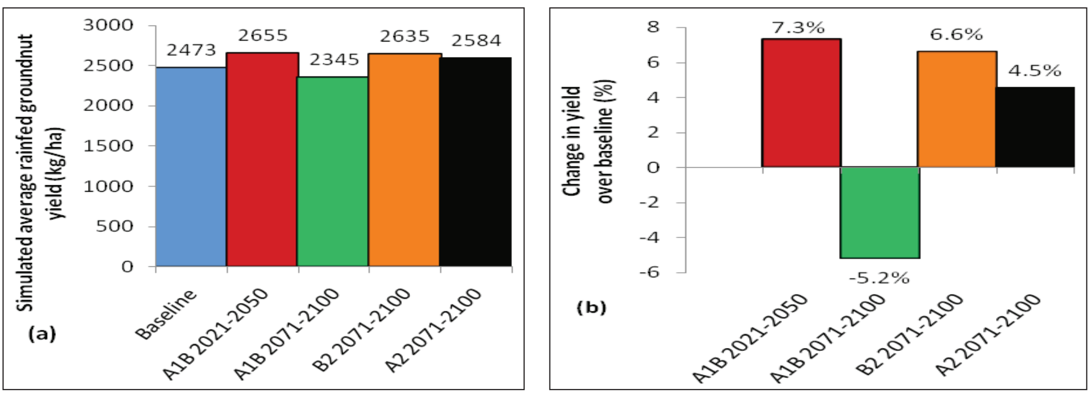


Fig.158. (a) Average simulated rainfed groundnut yields under current (baseline) and future climate scenarios and, (b) Projected average change in simulated groundnut yields under future climate scenarios as compared to the baseline in major crop growing regions of India

INDIAN INSTITUTE OF SUGARCANE RESEARCH
LUCKNOW

To provide an estimate of impact of climate change on sugarcane in states of Uttar Pradesh and Maharashtra based on literature review

Weather database collection

Long-term weather data-base from some locations in Uttar Pradesh was collected. The details of nature of data, frequency of data and duration of data is given in table 96. Besides, monthly rainfall data for state of Uttar Pradesh was also collected for the period 1976-2008 along with average productivity of sugarcane in the state.

Table 96. Details of weather data collected

S.No	Location	Weather parameter	Frequency	Duration
1	Allahabad	Maximum and minimum temperature, rainfall, number of rainy days	Monthly	1933-2006
2	Baharaich	Maximum and minimum temperature, rainfall, number of rainy days	Monthly	1970-2006
3	Ballia	Maximum and minimum temperature, rainfall, number of rainy days	Monthly	1957-2006
4	Banda	Maximum and minimum temperature, rainfall, number of rainy days	Monthly	1950-2005
5	Fathepur	Maximum and minimum temperature, rainfall, number of rainy days	Monthly	1933-2005
6	Ghazipur	Maximum and minimum temperature, rainfall, number of rainy days	Monthly	1979-2005
7	Gorakhpur	Maximum and minimum temperature, rainfall, number of rainy days	Monthly	1970-2006
8	Hardoi	Maximum and minimum temperature, rainfall, number of rainy days	Monthly	1952-2005
9	Lakhimpur-Khiri	Maximum and minimum temperature, rainfall, number of rainy days	Monthly	1951-2005
10	Lucknow	Maximum and minimum temperature, morning and afternoon relative humidity, duration of bright sunshine, wind speed, rainfall and number of rainy days	Daily	1979-2009
11	Muzaffarnagar	Maximum and minimum temperature, rainfall, number of rainy days	Monthly	1990-2007
12	Varanasi	Maximum and minimum temperature, rainfall, number of rainy days	Monthly	1933-2006

Temperature trends in Uttar Pradesh

The trend analysis was performed for maximum, minimum and average temperature for different locations. The trends analysis results are presented in table 97.

Table 97. Annual temperature trends in Uttar Pradesh

Parameter	Range	Mean	(±) SD	Trend line	Correlation (r)
Allahabad					
T_{max}	31.4-34.2	32.6	0.62	Y = 0.0082X + 16.364	0.2876***
T_{min}	18.5-21.2	19.7	0.58	Y = 0.0061X + 7.6313	0.2291**
$T_{average}$	25.1-27.2	26.2	0.48	Y = 0.0071X + 12.253	0.3159****
Baharaich					
T_{max}	30.1-32.6	31.5	0.53	Y = -0.0102X + 51.644	0.2057
T_{min}	18.7-21.4	19.5	0.52	Y = 0.0235X - 27.295	0.4928****
$T_{average}$	24.4-26.2	25.4	0.43	Y = 0.0116X + 2.3387	0.3283**
Ballia					
T_{max}	29.4-33.2	31.7	0.95	Y = -0.0412X + 113.33	0.6357****
T_{min}	15.1-20.4	18.6	1.19	Y = -0.0071X + 32.542	0.0866
$T_{average}$	22.0-26.7	25.0	0.90	Y = -0.0256X + 75.813	0.4147****
Banda					
T_{max}	26.2-34.8	33.3	1.66	Y = 0.0085X + 16.404	0.1127
T_{min}	17.3-21.1	19.7	0.82	Y = 0.0057X + 8.5474	0.1323
$T_{average}$	22.8-27.6	26.5	0.89	Y = 0.0068X + 13	0.1556
Fatehpur					
T_{max}	29.3-33.8	31.9	0.83	Y = -0.0087X + 49.217	0.2220*
T_{min}	13.6-21.7	18.7	1.56	Y = -0.0057X + 30.163	0.1005
$T_{average}$	22.3-27.4	25.3	1.03	Y = -0.0066X + 38.556	0.1628
Ghazipur					
T_{max}	28.3-32.6	30.6	1.38	Y = -0.0012X + 33.016	0.0071
T_{min}	15.2-20.3	17.6	1.24	Y = -0.0757X + 168.38	0.4491***
$T_{average}$	21.8-26.8	24.2	1.18	Y = -0.0486X + 120.93	0.3263*

Parameter	Range	Mean	(±) SD	Trend line	Correlation (r)
Gorakhpur					
T_{max}	30.4-33.2	31.9	0.66	Y = -0.0288X + 89.114	0.4721****
T_{min}	17.8-20.3	19.2	0.56	Y = 0.0295X - 39.358	0.5695****
$T_{average}$	24.4-26.5	25.5	0.42	Y = 0.0003X + 24.878	0.0084
Hardoi					
T_{max}	27.7-32.8	31.2	0.96	Y = -0.0317X + 93.972	0.5221****
T_{min}	17.4-20.1	19.0	0.56	Y = 0.0224X - 25.246	0.6333****
$T_{average}$	23.4-26.0	25.1	0.50	Y = -0.0047X + 34.363	0.1459
Lakhimpur-Khiri					
T_{max}	30.1-32.9	31.3	0.59	Y = -0.0159X + 62.679	0.4322****
T_{min}	18.6-19.9	19.1	0.32	Y = 0.0137X - 7.9798	0.6823****
$T_{average}$	24.6-25.9	25.2	0.32	Y = -0.0012X + 27.563	0.1459
Lucknow					
T_{max}	30.1-33.2	31.5	0.62	Y = -0.0373x + 105.73	0.5269****
T_{min}	15.7-19.1	18.1	0.65	Y = 0.0201x - 22.019	0.2718
$T_{average}$	23.9-25.6	24.8	0.43	Y = -0.0085x + 41.792	0.1732
Muzaffarnagar					
T_{max}	28.3-30.3	29.4	0.67	Y = 0.052X - 74.46	0.4099*
T_{min}	13.9-19.4	16.6	1.56	Y = 0.0226X - 28.528	0.0075
$T_{average}$	20.9-23.9	22.7	0.99	Y = 0.0578X - 92.748	0.3103
Varanasi					
T_{max}	30.8-33.6	32.1	0.56	Y= -0.0027X + 37.408	0.1029
T_{min}	17.1-20.9	19.6	0.76	Y = -0.0075X + 34.279	0.2114*
$T_{average}$	24.6-26.9	25.8	0.47	Y= -0.0051X + 35.843	0.2311**

****- significant at 1%, ***- significant at 2%, **-Significant at 5%, *-Significant at 10%

The annual maximum temperature reflected an increasing trend at Allahabad and Muzaffarnagar; a decreasing trend at Baharaich, Ballia, Fatehpur, Gorakhpur, Hardoi, Lakhimpur-Khiri and Lucknow and no trends were reflected at Banda, Ghazipur and Varanasi.

The annual minimum temperature an increasing trend at Allahabad, Baharaich, Gorakhpur, Hardoi, Lakhimpur-Khiri, Lucknow and Muzaffarnagar, a decreasing trend at Ghazipur and Varanasi and no trend at Ballia, Banda and Fatehpur.

The annual average temperature reflected an increasing trend at Allahabad, Baharaich and Muzaffarnagar, a decreasing trend at Ballia, Fatehpur, Ghazipur, Hardoi, Lucknow and Varanasi and no trend at Banda, Gorakhpur and Lakhimpur-Khiri.

Average rainfall trend in Uttar Pradesh

The monthly rainfall data (1976-2008) for Uttar Pradesh was analyzed for trend in calendar months, monsoon season and annual rainfall. The range, mean, CV and rate of variation is shown in table 98.

Table 98. Range, mean, CV and rate of change of rainfall in Uttar Pradesh

Months	Rainfall (mm)		% CV	Rate (mm/year)
	Range	Mean		
January	0.1-75.5	16.1	93.4	-0.67
February	0.0-63.4	19.2	89.4	-0.34
March	0-55.5	12.7	114.7	-0.56
April	0.3-72.1	10.8	140.4	-0.66
May	2.3-139.4	25.7	104.1	-1.21
June	25.8-284.1	106.2	51.9	-0.55
July	70.1-456.0	269.3	32.6	-3.23
August	109.7-434.0	249.0	33.1	-1.81
September	28.4-350.1	168.2	41.8	-2.19
October	0.2-160.9	28.1	114.6	-0.37
November	0.0-25.1	4.2	159.0	-0.20
December	0.0-59.7	9.4	131.1	-0.37
Monsoon	482.2-1206.3	792.8	21.4	-7.77
Annual	536.9-1377.2	918.9	21.6	-12.15

Data Source: UP Council of Agricultural Research, Lucknow

The rainfall reflected a declining trend in all calendar months. During monsoon season, the highest rate of decline of 3.23 mm/year was noticed for the month of July and lowest rate of 0.55 mm/year in the month of June. The rate of decline of nearly 7.8 and 12.2 mm/year was noticed, respectively for monsoon and annual rainfall. The pattern of monsoon and annual rainfall is shown in Fig.159 (a&b).

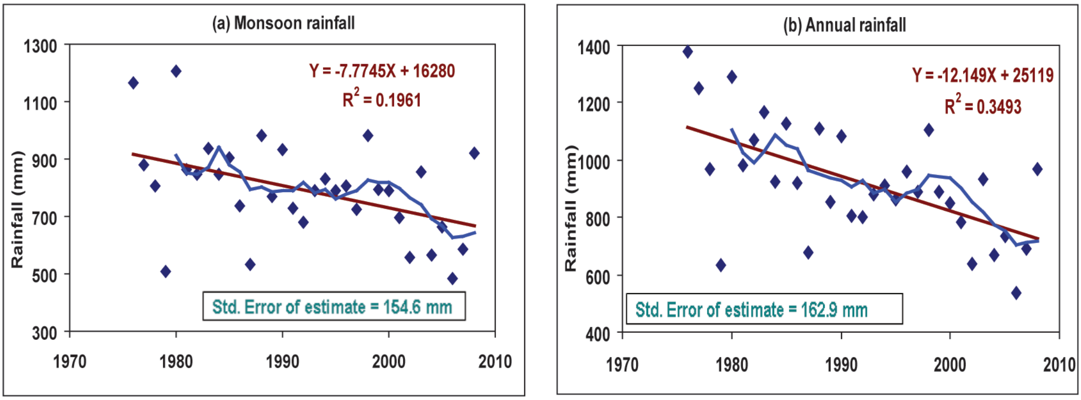


Fig. 159. Rainfall trend in Uttar Pradesh (a) Monsoon (b) Annual

Effect of rainfall on sugarcane yield in Uttar Pradesh

The rainfall and cane yield relationship was studied in terms of correlations with monthly rainfall from April to September, the period comprising of shoot formation and crop elongation phases, the main components contributing to yield. The correlations based on database from 1976-2008 are presented in table 99.

Table 99. Correlation between monthly rainfall and cane yield

Month	Correlation (r)
April	-0.3197
May	-0.3486*
June	-0.2293
July	-0.3475*
August	0.0226
September	-0.2185
March-May	-0.4774***
Monsoon	-0.2947
Annual	-0.3984*

*- Significant at 5% ***- Significant at 1%

The correlation of yield with rainfall received during March to May is highly significant. This period coincides with shoot formation (tillering) phase of the crop. The further analysis indicated that if the total rainfall during this period exceeds 50 mm, it might depress the yield at harvest.

Effect of July rainfall on sugarcane productivity in UP

The impact of July rainfall was assessed on average sugarcane productivity in the state of Uttar Pradesh as rainfall in July triggers the elongation phase of the crop. The correlation between %deviation in rainfall from long-term normal rainfall of July and sugarcane productivity was = -0.4082 (significant at 5%). The following linear regression between cane yield (Y) and %deviation of rainfall (X) in July from long-term normal was obtained.

$$Y = -0.0681X + 54.234 \ (R^2 = 0.1666 \ df = 30)$$

Effect of annual rainfall on cane yield in UP

The correlation (r = -0.3984) between annual rainfall and cane yield was significant (at 5%). The following linear regression between cane yield (Y) and annual rainfall (X) was obtained.

$$Y = -0.0135X + 65.686 \ (R^2 = 0.1587 \ df = 31)$$

The average cane productivity was 56.6 (± 5.9) t ha^{-1} when annual rainfall received was up to 900 mm. The average cane yield was 50.9(± 7.4) t ha^{-1} when rainfall was between 900-1000mm. With rainfall exceeding 1000 mm, the average productivity was 49.4(± 4.9) t ha^{-1}.

To calibrate and validate DSSAT and WOFOST models for sugarcane

The CANEGROW (DSSAT model, ver 4.5) was calibrated for sugarcane varieties CoJ 64, CoLk 8102 for Lucknow conditions and CoSe92423 for Seorahi (Eastern UP) conditions from basic crop data available from literature. Some of coefficients used in the model are given in table 100.

Table 100. Genetic coefficients of sugarcane varieties used in CANEGROW (DSSAT model, ver 4.5)

Genetic Coefficients	Varieties		
	CoJ 64	**CoLk 8102**	**CoSe 92423**
PARCE max (Maximum (no stress) radiation use efficiency expressed as assimilate produced before respiration, (g/MJ))	8.50	8.95	8.4
APFMX (maximum fraction dry mass increments allocated to aerial dry mass (t/t))	0.86	0.88	0.88
STKPFMAX (fraction of daily aerial dry mass increments partitioned to stalk at high temperature in mature crop, (t/t on dry weight basis)	0.60	0.65	0.65
Thalfo (Thermal time to half canopy, ^oCd)	250	250	250
Tbase (Base temperature to canopy development ^oC)	16.0	16.0	16.0
LFMAX (maximum number of green leaves in a healthy, well water plant before it is to lose some leaves	11	12	12

Genetic Coefficients	Varieties		
	CoJ 64	CoLk 8102	CoSe 92423
MXLFAREA (maximum life area assigned to leaves cm^2)	355	360	360
MXLFARNO (leaf number above which leaf area in limited to MXLFAREA	14	15	16
TTBASELFEX (Phyllochron interval 1 for leaf below Pswitch, ^oCd)	95	92	100
TTBASELFEX (Phyllochron interval 2) (for leaf below PI2, ^oCd)	180	175	200
PSWITCH (leaf number at which the phyllochron changes)	15	16	15
MAX_POP (maximum tiller production, shoots/m^2)	25	26.5	23
POPTT16 (stalk population at/after 1600 ^oCd, stalk/m^2)	10.3	11.5	9.5
TTPNTEM (thermal time to emergence for plant crop, oCd)	340	350	360
CHUPIBASE (thermal time from emergence to start of stalk growth, ^oCd)	1850	1710	1680
TT_POPGROWTH (thermal time to peak tiller population, ^oCd)	670	620	600

DSSAT run results

The summary of results is presented in table 101.

Table 101. Summary of model out put

Location	Crop season	Variety /planting season	Crop yield (t ha^{-1})	
			Model estimate	Observed
Lucknow	1992-94	CoLk 8102 (A)	72.2	87.9
	1992-94	CoJ 64 (A)	59.3	58.3
	1993-94	CoLk 8102 (S)	69.0	72.5
	1993-94	CoJ 64 (S)	59.3	59.9
Seorahi	2006-07	CoSe92423 (S)	66.2	72.2

A- Autumn plating (26th October), S- Spring planting (25th Feb at Lucknow and 15th Feb at Serorahi)

The model under estimated the yield of autumn and spring planted sugarcane for CoLk 8102 at Lucknow by 17.8 and 4.8 % respectively. The estimates for Co J 64 are quite close to observed yield. For Seorahi spring crop stand the model under estimated the yield by 8.2 %.

To develop sugarcane simulation module with INFOCROP frame work

The basic information on crop parameters have been collected from experimental trials conducted at IISR, Lucknow and Genda Singh Sugarcane Research Institute, Seorahi (in eastern U P) for sugarcane varieties CoJ 64, CoLk 8102 and CoSe 82423. Some of the crop genetic coefficients for these varieties have been used in CANEGROW DSSAT model with encouraging results. Besides, impact of leaf temperature and PAR on rate of photosynthesis in early crop phases in sugarcane under Lucknow conditions have also been worked out (Fig. 160 (a &b)).

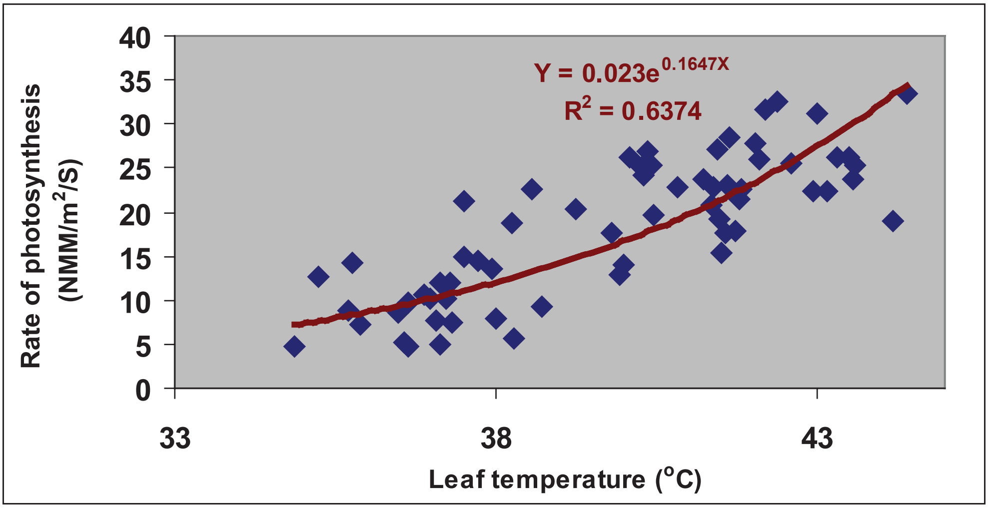


Fig.160(a). Leaf temperature and rate of photosynthesis in sugarcane

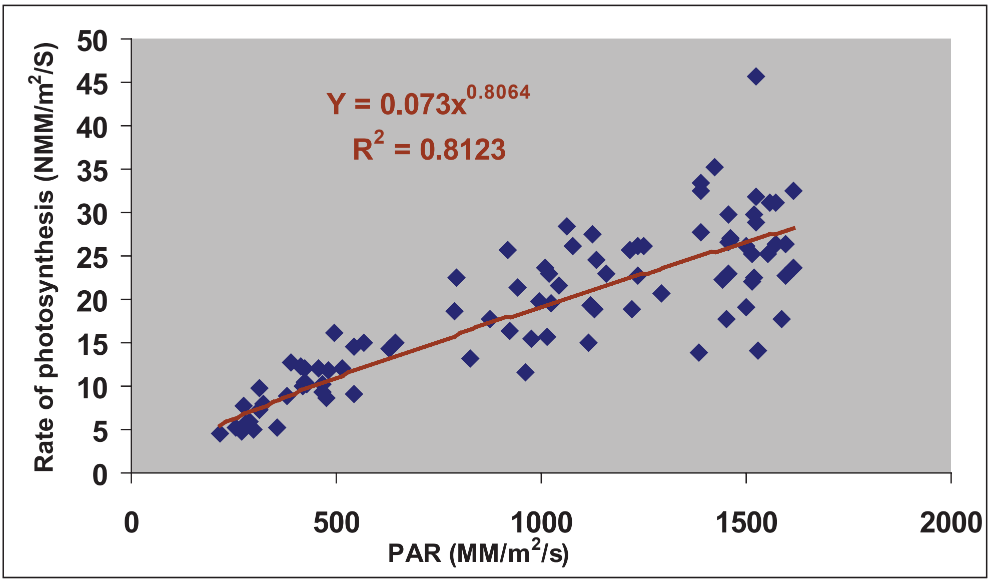


Fig 160(b). PAR and rate of Photosynthesis

To quantify the suitability of various agronomic measures for adaptation to climate change

Sugarcane, being a long-duration crop, encounters all the major seasons during its life cycle. The formative phase of the crop coincides with hot summer months and irrigation becomes most critical both in terms of water availability and its quality. Some of the agronomic measures like, ring- pit planting method (T1), trash mulching (T2), skip-furrow method of irrigation (T3) and irrigation at critical growth stages (T4) have been suggested to effectively address these issues. The relevant data on the effect of these technologies on cane productivity, water saving and water use efficiency is given in table 102.

Table 102. Effect of irrigation methods on sugarcane yield, water saving and water use efficiency

Agronomic measure	No. Demo.	Cane Yield (t ha^{-1})			Water applied (cm)			IWUE (kg $ha^{-1}cm^{-1}$)		
		D	C	% Increase	D	C	Saving (%)	D	C	Increase (%)
T1	2	116.0	70.0	65.7	37.5	61.0	38.52	2626.7	1147.5	128.9
T2	10	75.92	54.92	38.2	42.5	59.6	28.7	1786.4	921.5	93.9
T3	14	82.8	63.7	30.0	48.7	63.9	31.2	1700.2	996.9	70.6
T4	9	82.8	63.4	30.6	46.0	55.3	16.81	1800.0	1146.5	57.0

D- demonstration, C-conventional and IWUE- Irrigation water use efficiency

Source: Annual Report (2008-09) IISR, Lucknow

The economics of these agronomic is presented in table 103.

Table 103. Economics of some agronomic measures on sugarcane production (Plant cane)

Economic parameter	Farmers' practice	Demonstrated agronomic measure			
		Trash mulching	Ring-pit	ICGS	Skip furrow
Cost of Production (Rs ha^{-1})	56721.0	43034.0	88037.0	58790.0	54831.0
Cane yield (t ha^{-1})	65.7	75.9	116.0	82.8	82.8
Gross return (Rs ha^{-1})	91980.0	106288.0	162400.0	115920.0	115920.0
Net return (Rs ha^{-1})	35259.0	63254.0	74363.0	57130.0	61089.0
Benefit: Cost ratio	1.62	2.47	1.85	1.97	2.11

To collect and compile relevant indigenous traditional knowledge on sugarcane crop

A total of thirty themes on ITK covering climate and weather, crop nutrition and tillage operations were collected from published records, interactions with farmers, sugarcane development workers and other available sources. Besides, eleven recent observations from farmers on sugarcane crop culture were also collected. The detailed compilation on ITK is enclosed separately.

PUNJAB AGRICULTURAL UNIVERSITY
LUDHIANA

Objective : To provide a first estimate of impact of climate change on important commodities based on literature review and expert judgement

Salient findings :

The time trend equations for various meteorological parameters at different locations are shown in the tables 1, 2 and 3. The results of the study were:

- At Ludhiana the kharif season maximum temperature has decreased from the normal at the rate of 0.01 ^{o}C / year and the *rabi* season maximum temperature has increased from the normal at the rate of 0.02 ^{o}C / year. So overall no significant changes in maximum temperature were noted at Ludhiana.
- In general, the maximum temperature has decreased from the normal at Ballowal Saunkhri and Bathinda, however, for other locations no trend could be established. The *kharif* maximum temperature decreased at the rate of 0.04 ^{o}C/year at Ballowal Saunkhri and Bathinda.
- The annual and seasonal minimum temperature has increased at the rate of 0.07 ^{o}C / year over the past three decades at Ludhiana. At Patiala the annual and *kharif* minimum temperature has increased at the rate of 0.02 ^{o}C / year and at Bathinda the annual, *kharif* and *rabi* minimum temperature has increased at the rate of about 0.03, 0.02 and 0.05 ^{o}C/year, respectively.
- The analysis of past 108 years rainfall data at Ludhiana revealed that the annual, kharif and summer season rainfall at Ludhiana has increased from the normal at the rate of 1.4, 1.7 and 1.4 mm/ year, respectively. But the *rabi* and winter season season rainfall at Ludhiana has either decreased slightly from the normal or not changed significantly over the past 108 years.
- However for other locations no significant change was noted for annual and seasonal rainfall over the past three decades. At Ballowal Saunkhri the annual, *kharif* and *rabi* rainfall has decreased at the rate of 16, 12 and 3 mm/year, respectively. At Bathinda *rabi* season rainfall has decreased at the rate of 2 mm/year over the past three decades.
- The annual, kharif and rabi season morning relative humidity at Ludhiana has increased from the normal at the rate of 0.12, 0.16 and 0.08 percent/ year, respectively and the annual, *kharif* and *rabi* season evening relative humidity at Ludhiana has increased from the normal at the rate of 0.22, 0.24 and 0.20 percent/ year respectively over the past three decades.
- The solar radiation at Ludhiana revealed no significant changes in the past three decades. However, a slight decreasing trend in annual and seasonal solar radiation was noted. Over the past 38 years, the annual, *kharif* season (summer season) and the *rabi* season (winter season) solar radiation has decreased from the normal at the rate of 0.02, 0.01 and 0.03 MJ/m^2/year.
- The perusal of the data on pan evaporation at Ludhiana revealed that the annual, *kharif* and the *rabi* season pan evaporation has decreased from the normal at the rate of 0.02, 0.03 and 0.01 mm/ year. The decrease in pan evaporation especially in *kharif* season can be attributed to decreasing solar radiation trends (Table 104 – 106).

Table 104. Time trend equations for meteorological parameters at Ludhiana (1970-2008)

Meteorological parameters	Annual	*Kharif* season	*Rabi* season
Maximum temperature[1]	$Y = 0.0014X + 26.884$ $R^2 = 0.0031$	$Y = -0.013X + 60.698$ $R^2 = 0.2068$	$Y = 0.02X - 15.297$ $R^2 = 0.2221$
Minimum temperature[1]	$Y = 0.0684X - 119.59$ $R^2 = 0.9201$	$Y = 0.072X - 120.14$ $R^2 = 0.9256$	$Y = 0.0667X - 122.98$ $R^2 = 0.8705$
Morning Relative humidity[2]	$Y = 0.129X - 173.95$ $R^2 = 0.6431$	$Y = 0.1647X - 250.33$ $R^2 = 0.5938$	$Y = 0.0845X - 80.059$ $R^2 = 0.5168$
Evening Relative humidity[2]	$Y = 0.2261X - 404.53$ $R^2 = 0.8519$	$Y = 0.2462X - 442.37$ $R^2 = 0.7655$	$Y = 0.2024X - 359.36$ $R^2 = 0.6266$
Pan Evaporation[3]	$Y = -0.0278X + 59.979$ $R^2 = 0.5194$	$Y = -0.0346X + 75.121$ $R^2 = 0.581$	$Y = -0.0168X - 36.668$ $R^2 = 0.3014$
Solar Radiation[4]	$Y = -0.0238X + 63.851$ $R^2 = 0.1074$	$Y = -0.0145X + 47.744$ $R^2 = 0.0324$	$Y = -0.0301X + 74.106$ $R^2 = 0.1573$

1 - Slope of regression in °C/calendar year
2 - Slope of regression in %/calendar year
3 - Slope of regression in mm/calendar year
4 - Slope of regression in MJ m^2/calendar year

Table 105. Time trend equations for rainfall (slope of regression in mm/calendar year) analysis at Ludhiana (1901-2008)

Time Period	Variability Trend
Annual	$Y = 1.4662X - 2153.3$ $R^2 = 0.337$
Kharif season	$Y = 1.7855X - 2900$ $R^2 = 0.435$
Monsoon season	$Y = 1.4106X - 2204.5$ $R^2 = 0.417$
Rabi season	$Y = -0.0681X + 258.23$ $R^2 = 0.0059$
Winter season	$Y = -0.1185X + 336.45$ $R^2 = 0.0306$

Table 106. Time trend equations for temperature and rainfall over the past three decades at different locations in Punjab

Station	Annual	*Kharif*	*Rabi*
Maximum Temperature ((slope of regression = °C/calendar year)			
Ballowal Saunkhri (31° 60' N, 76° 23' E, 355m)	$Y = 0.058X - 86.08$ $R^2 = 0.46$	$Y = 0.045X - 56.17$ $R^2 = 0.46$	$Y = 0.089X – 152.30$ $R^2 = 0.56$
Amritsar (31° 37' N, 74° 53' E, 231 m)	$Y = -0.010X + 50.97$ $R^2 = 0.13$	$Y = -0.018X + 73.07$ $R^2 = 0.32$	$Y = 0.007X + 10.39$ $R^2 = 0.05$
Patiala (30° 20' N 76° 28' E 251 m)	$Y = 0.004X + 21.10$ $R^2 = 0.04$	$Y= -0.007X + 50.33$ $R^2 = 0.17$	$Y = 0.020X - 16.39$ $R^2 = 0.26$
Bathinda (30° 12' N 74° 57' E 211 m)	$Y = -0.023X + 77.42$ $R^2 = 0.21$	$Y = -0.040X + 117.00$ $R^2 = 0.31$	$Y = -0.001X + 29.41$ $R^2 = 0.00$
Minimum Temperature (slope of regression = °C/calendar year)			
Ballowal Saunkhri (31° 60' N, 76° 23' E, 355m)	$Y = -0.022X + 61.80$ $R^2 = 0.06$	$Y = -0.011X + 45.87$ $R^2 = 0.02$	$Y = -0.008X + 27.25$ $R^2 = 0.006$
Amritsar (31° 37' N, 74° 53' E, 231 m)	$Y = -0.004X + 25.17$ $R^2 = 0.017$	$Y = -0.002X + 28.13$ $R^2 =0.004$	$Y = -0.006X + 21.01$ $R^2 = 0.02$
Patiala (30° 20' N 76° 28' E 251 m)	$Y = 0.015X - 13.34$ $R^2 = 0.43$	$Y = 0.022X - 20.81$ $R^2 = 0.59$	$Y = 0.010X - 9.803$ $R^2 = 0.15$
Bathinda (30° 12' N 74° 57' E 211 m)	$Y = 0.038X - 59.57$ $R^2 = 0.59$	$Y = 0.025X - 27.30$ $R^2 = 0.25$	$Y = 0.053X - 97.18$ $R^2 = 0.71$
Rainfall (slope of regression = mm/calendar year)			
Ballowal Saunkhri (31° 60' N, 76° 23' E, 355m)	$Y = -16.11X + 3314$ $R^2 = 0.39$	$Y = -12.50X + 25948$ $R^2 = 0.34$	$Y = -3.26X + 6675$ $R^2 = 0.36$
Amritsar (31° 37' N, 74° 53' E, 231 m)	$Y = -1.94X + 4579$ $R^2 = 0.06$	$Y = -1.32X + 3210$ $R^2 = 0.04$	$Y = -1.18X + 2493$ $R^2 = 0.06$
Patiala (30° 20' N 76° 28' E 251 m)	$Y = 1.08X – 1358$ $R^2 = 0.007$	$Y = 2.25X - 3824$ $R^2 = 0.038$	$Y = -1.462X+ 3044$ $R^2 = 0.054$
Bathinda (30° 12' N 74° 57' E 211 m)	$Y = -3.015X + 6562$ $R^2 = 0.034$	$Y = -0.276X + 1009$ $R^2 = 0.00$	$Y = -2.976X + 6025$ $R^2 = 0.54$

Objective : **To calibrate and validate InfoCrop model for key food crops in different agroclimatic regions of the state**

Salient findings

The InfoCrop model was validated by comparing the model simulated and actual observations w.r.t. to phenology, growth and yield of wheat cultivars, viz PBW-343, PBW-502 and PBW-550 for different environments. The phenological events, i.e., anthesis date and physiological maturity date simulated by InfoCrop model and those actually observed in the field for wheat cultivars are given in Fig.161 and 162, respectively. The model gave overestimation as well as underestimation of these events. The anthesis and physiological maturity dates were simulated between -15 to +4 days and -13 to +14 days, respectively of the actual observed dates for wheat cultivars under different environments.

The growth and yield attribute, i.e., maximum LAI and grain yield simulated by InfoCrop model and those actually observed in the field for wheat cultivars are given in Fig.163 and 164, respectively. The model gave overestimation as well as underestimation of these events. The maximum LAI was simulated between -23 to +39 % of the actual observed data for wheat cultivars under different environments. Grain yield was simulated within -17 to +17 % of the actual observed grain yield for October and November sown wheat crop. However, the model gave very low grain yield for wheat cultivars sown in December month.

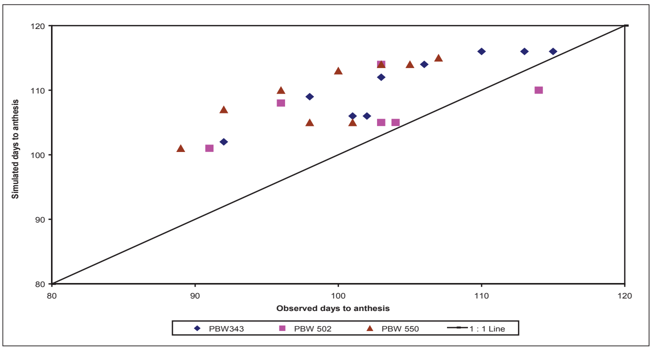


Fig.161. Comparison of observed and simulated days to anthesis of wheat cultivars under different environments using the INFOCROP model (*Rabi* 2006-07, 2007-08 and 2009-10)

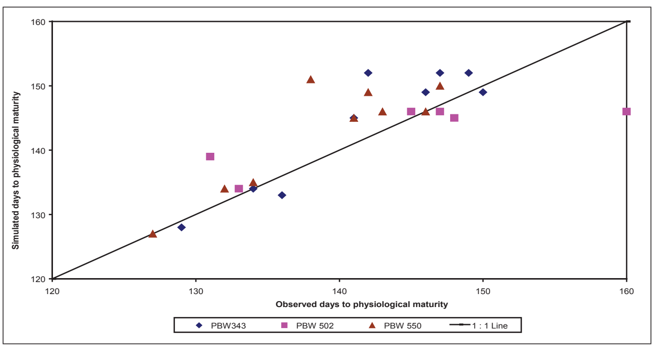


Fig.162. Comparison of observed and simulated days to physiological maturity of wheat cultivars under different environments using the INFOCROP model (*Rabi* 2006-07, 2007-08 and 2009-10)

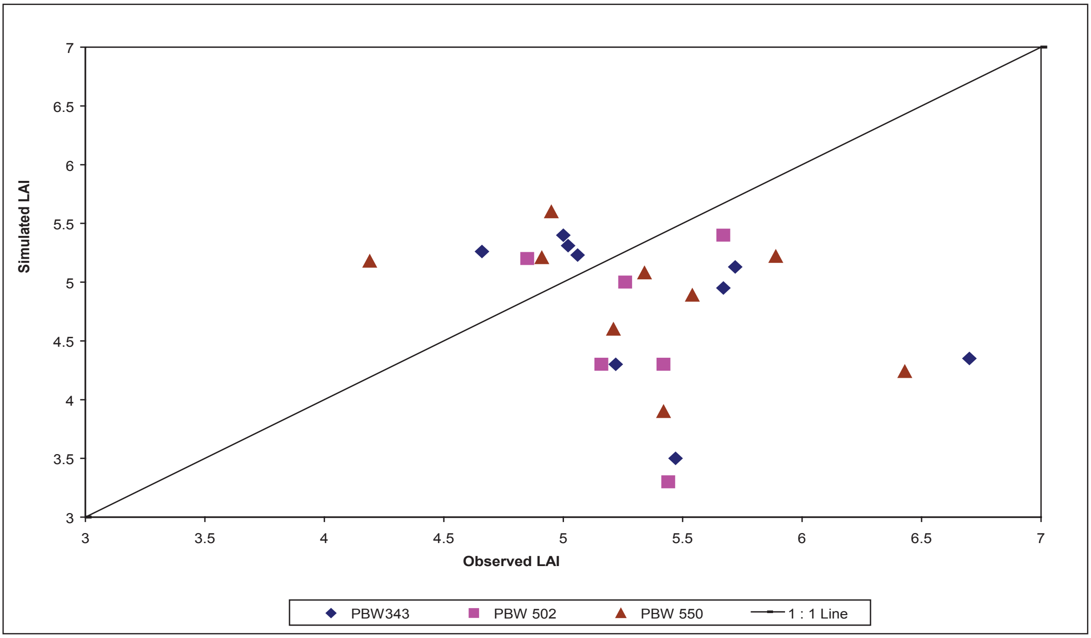


Fig.163. **Comparison of observed and simulated maximum Leaf Area Index (LAI) of wheat cultivars under different environments using the INFOCROP model (*Rabi* 2006-07, 2007-08 and 2009-10)**

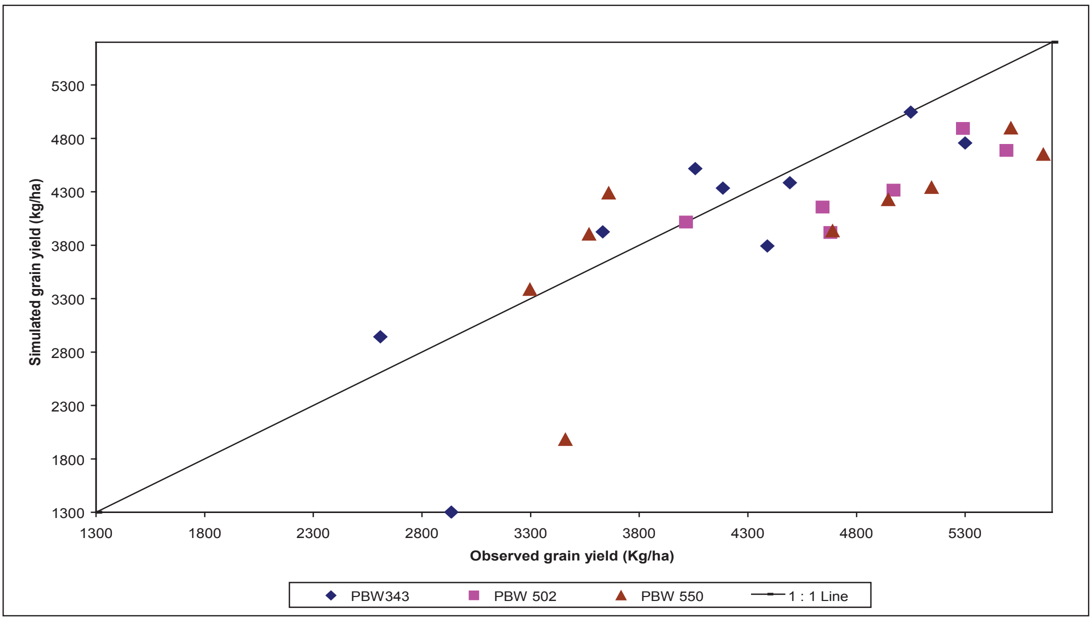


Fig.164. **Comparison of observed and simulated grain yield of wheat cultivars under different environments using the INFOCROP model (*Rabi* 2006-07, 2007-08 and 2009-10)**

Objective : To conduct Farmer's Awareness Programme on Climate Change in the state

Special lectures delivered by the project team members during "Farmer's Awareness Program on Climate Change" at Krishi Vigyan Kendra's of the university.

- Dr Prabhjyot Kaur Sidhu delivered lecture on "Impact of Climate Change on Agriculture" at Krishi Vigyan Kendra, Rauni on 16 September 2009
- Dr Prabhjyot Kaur Sidhu delivered lecture on "Mausami Badlaw – Kaaran ate Vishleshan (Climate change – Reasons and their analysis)" at Krishi Vigyan Kendra, Fathegarh Sahib on 9 October 2009.
- Sh Harpreet Singh delivered lecture on "Mausami Tabdelian da Kheti Baari te parbhaw (Impact of climate change on agriculture)" at Krishi Vigyan Kendra, Fathegarh Sahib on 9 October 2009.
- Dr Prabhjyot Kaur Sidhu delivered lecture on "Mausami Tabdelian da Kheti Baari te parbhaw (Impact of climate change on agriculture)"at Krishi Vigyan Kendra, Langroya on 19 January 2010.
- Dr Prabhjyot Kaur Sidhu delivered lecture on "Mausami Badlaw – Kaaran ate Vishleshan (Climate change – Reasons and their analysis)" at Krishi Vigyan Kendra, Amritsar on 24 February 2010.
- Sh Harpreet Singh delivered lecture on "Mausami Tabdelian da Kheti Baari te parbhaw (Impact of climate change on agriculture)" at Krishi Vigyan Kendra, Amritsar on 24 February 2010.

Objective : To examine the relationship between the impact of climate change on production / availability and food vulnerability in different economic groups

A complete list of all the possible indicators which are expected to influence vulnerability of a region/area has been prepared. The list includes various indicators pertaining to agriculture, climate, demographic characteristics, health and marketing. A description of all the variables which may represent the selected indicator has been given in the following Table. In addition, the possible impact of these variables on the extent of vulnerability has been given as these variables can contribute to the extent of vulnerability in two manners. Some of the variables may help in reducing the vulnerability and the other may increase it.

Salient findings

The district-wise data on all these variables has been collected and the vulnerability indices are being constructed (Table 107). First, the indices will be constructed for the current period. Later, an attempt will be made to analyze the trends in vulnerability over time by utilizing the time-series data for Punjab. The time-series data will pertain to the time period ranging from 1970-71 till date. The time trends will throw light on how various districts have performed w.r.t. to vulnerability and what were the strategies to reduce vulnerability at the macro level.

Table 107. List of possible indicators for construction of Vulnerability Index for Punjab

Category	Indicator	Description of the Variable	Impact on Agriculture (Its contribution to vulnerability)
AGRICULTURE	Irrigation	Net irrigated area as % of NAS	Increased irrigation reduces vulnerability
		GIA divided by NIA (irrigation intensity)	Same as above
	Food Production and Productivity	Area under food crops	Increased area under food crops reduces vulnerability
		Food production per hectare	Same as above
		Farm incomes per ha	Same as above
		Gross value of agricultural output per ha	Same as above
		Share of agricultural GDP	
	Consumption of fertilizer per hectare	Fertilizer consumption per hectare	Increased fertilizer consumption reduces vulnerability
	Land use	Geographical area	Same as above
		Average farm size	Same as above
		Area not cultivated as % of total area	Increase in uncultivated area increases vulnerability
		% area under rice and wheat or major food crops	Increase in area reduces vulnerability
		Forest area as % of the geographical area	Same as above
		% of small and marginal farmers	Increased proportion of small and marginal farmers increases vulnerability
		% of land cultivated by small and marginal farmers	Increase in area reduces vulnerability
		Cropping intensity	Increased CI reduces vulnerability
		Number of farmers per ha of area cultivated	More number of farmers increases vulnerability
	Composition of Workers	Number of labourers are available for agricultural activities	
		Number of industrial workers	
		Number of marginal workers	More number increases vulnerability
		Number of non workers	Same as above

Category	Indicator	Description of the Variable	Impact on Agriculture (Its contribution to vulnerability)
OTHER AGRICULTURAL	Number of cows used for milk production that gives the additional income to the farmers	Number of milch animals	Reduces vulnerability
	Amount of credit Received	Amount of credit Received per ha	Reduces vulnerability
CLIMATE	Changes in the Temperature	Change in Max Temp	Rising temp increases vulnerability
		Change in Min Temp	Same as above
	Rainfall	Change/extent of rainfall	Decline in rainfall increases vulnerability
		Rainfall in the monsoon period	Same as above
	Relative Humidity	Changes in Maximum RH	Increase in RH increases vulnerability
		Changes in Minimum RH	Same as above
DEMOGRAPHIC & HEALTH	Literacy	Literacy rate	Higher literacy reduces vulnerability
	Population density	Population density	More population density increases vulnerability
	Poverty	% population below poverty line	Increased poverty increases vulnerability
	Life expectancy	Life expectancy	Increased life expectancy reduces vulnerability
		Infant mortality rate	Increased IM increases vulnerability
MARKETING	Distance travelled to market to sell the produce	Area served per market	Less area served per market reduces vulnerability

CSK HIMACHAL PRADESH AGRICULTURE UNIVERSITY
PALAMPUR

Objective: Impact of climate change scenarios on rice productions and adaptations measures simulated for late sown wheat and rice

Salient findings:

Validation of crop model for rice (*Kharif*) crop

The observed field data from year 2000 to 2001 was used to validate the INFOCROP Model for rice crop. Simulated and observed days to maturity, anthesis and yield for rice crop at Palampur were compared (Table 108, 109 &110). To asses the impact of elevated carbon dioxide and temperature and rainfall variability, the crop model was run for year 2000 and 2001.

Table 108. Simulated and Observed days to maturity for rice crop in Palampur

S. No	Planting date	Simulated	Observed
1.	10th June 2000	106	97
2.	20th June 2000	109	99
3.	30th June 2000	114	106
4.	10th July 2000	122	110
5.	10th June 2001	103	96
6.	20th June 2001	109	102
7.	30th June 2001	114	106
8.	10th July 2001	119	106

RMSE = 9.5

Table 109. Simulated and Observed days to anthesis for rice crop in Palampur

S. No	Planting date	Simulated	Observed
1.	10th June 2000	68	64
2.	20th June 2000	69	64
3.	30th June 2000	72	69
4.	10th July 2000	76	72
5.	10th June 2001	65	59
6.	20th June 2001	69	61
7.	30th June 2001	71	65
8.	10th July 2001	74	66

RMSE = 5.8

Table 110. Simulated and Observed yield for rice crop in Palampur

S. No	Planting date	Simulated	Observed
1.	10th June 2000	3722.4	3581
2.	20th June 2000	3996.2	3853
3.	30th June 2000	3747.5	3625
4.	10th July 2000	2451.6	3208
5.	10th June 2001	3092.7	2985
6.	20th June 2001	3828.9	3808
7.	30th June 2001	3506.5	3260
8.	10th July 2001	1297.9	2995

RMSE =669.0

Salient Findings

Planting windows

The simulated results of rice crop yield indicated that 20th June transplanted crop to be the best transplanting window for rice followed by 30th June under Palampur conditions. The days taken for anthesis and maturity during 10th June transplanted crop were 66 and 104 followed by 20th June were 70 and 110. Whereas, 30th June and 10th July transplanted rice took 72 and 75 days for anthesis and 115 and 120 days for maturity, respectively (Table 111). With delay of 10 days transplanting 4 – 5 days in maturity and anthesis were increased.

Table 111. Impact of planting windows on days to anthesis, maturity and yield of rice crop

Planting window	Days to anthesis	Days to maturity	Yield (kg/ha)
10th June	66	104	3085.9
20th June	70	110	3776.6
30th June	72	115	3549.9
10th July	75	120	3336.1

Impact of elevated carbon dioxide levels

The elevated levels of carbon dioxide (50 and 100 ppm) took equal number of days for anthesis and maturity when compared with 370 ppm CO_2 level (Table 112). Elevated carbon dioxide levels of (50 and 100 ppm) showed an increase in yield of rice in all the transplanting windows from June 10th to July 10th. The 50 ppm and 100 ppm elevated levels of carbon dioxide increased yield by 7.6 to 11.7 % and 14.8 to 20.8 % in rice crop under rainfed conditions (Table 113).

Table 112. Impact of elevated CO_2 (420 ppm & 470 ppm) level on days to anthesis and maturity of rice crop

Planting window	Days to anthesis			Days to maturity		
	Control	420 ppm	470 ppm	Control	420 ppm	470 ppm
10th June	66	66	66	104	104	104
20th June	70	70	70	110	110	110
30th June	72	72	72	115	115	115
10th July	75	75	75	120	120	120

Table 113. Impact of elevated CO_2 (420 ppm & 470 ppm) level on rice yield

Planting window	Grain yield (kg/ha)			Percent increase/decrease	
	Control	420 ppm	470 ppm	50 ppm	100 ppm
10th June	3085.9	3445.5	3729.2	11.7	20.8
20th June	3776.6	4069.9	4337.7	7.8	14.8
30th June	3549.9	3821.1	4085.4	7.6	15.1
10th July	3336.1	3662.6	3881.9	9.8	16.4

Impact of elevated temperature

The two levels of elevated temperature by 1°C and 2°C were studied. The simulated days to anthesis, maturity and yield with 1°C and 2°C rise in temperature were compared with no change in temperature of 2009 under rainfed conditions. The increase of 1°C temperature showed advancement of 6 to 9 days in maturity and 3 to 4 days in anthesis where as, 2°C rise in temperature advanced the maturity by 5 to 14 days and anthesis by 6 to 7 days (Table 114). The increase in yield was 6.8 to 25 % with 1°C and 14.8 to 35.6 % in 2 °C rise in all transplanting windows (Table 115).

Table 114. Impact of elevated 1 °C and 2 °C rise temperature on days to anthesis and maturity of rice crop

Planting window	Days to anthesis			Days to maturity		
	Control	1 °C	2 °C	Control	1 °C	2 °C
10th June	66	63	60	104	98	93
20th June	70	66	63	110	103	98
30th June	72	68	65	115	106	100
10th July	75	71	68	120	113	106

Table 115. Impact of elevated 1 °C and 2 °C rise temperature on rice yield

Planting window	Grain yield (kg/ha)			Percent increase/decrease	
	Control	1 °C	2 °C	1 °C	2 °C
10th June	3085.9	2314.5	1987	-25	-35.6
20th June	3776.6	3439.7	3217.7	-8.9	-14.8
30th June	3549.9	3309.9	2658.8	-6.8	-25.1
10th July	3336.1	2787.6	2717.6	-16.4	-18.5

Impact of elevated temperature and carbon dioxide levels

The temperature rise of 1°C and 2°C coupled with 50 ppm elevated carbon dioxide (Table 117) caused reduction in the rice yield in almost all the transplanting windows. The reduction was more in 2°C (6.5 to 25.9 %) than 1°C (6.9 to 14.9 %) rise in temperature. The further increase in carbon dioxide level, to 100 ppm from control of 370 ppm with temperature rise of 1°C showed increase in the yield to the tune of 3.3 to 9.5 % in all the transplanting windows except 10th June transplanting window which showed reduction in the yield of 4.8 percent (Table 119). Whereas, with the rise of 2°C temperature the 20th June transplanting showed increase in the yield among all transplanting windows. One degree rise in temperature + 50 ppm higher level of CO_2 advanced the maturity of the crop by 6 to 9 days whereas; two degree rise + 50 ppm CO_2 advanced the maturity by 5 to 14 days (Table 116). Further increase of carbon dioxide to 100 ppm showed similar number of days in advancing the maturity period (Table 118).

Table 116. Impact of elevated CO_2 (420 ppm) and 1°C & 2°C rise temperature on days to anthesis and maturity of rice crop

Planting window	Days to anthesis			Days to maturity		
	Control	420 ppm		Control	420 ppm	
		1 °C	2 °C		1 °C	2 °C
10th June	66	63	60	104	98	93
20th June	70	66	63	110	104	97
30th June	72	68	65	115	106	100
10th July	75	71	68	120	113	106

Table 117. Impact of elevated CO_2 (420 ppm) and 1°C & 2°C rise temperature on rice yield

Planting window	Grain yield (kg/ha)			Percent increase/decrease	
	Control	420 ppm		420 ppm	
		1 °C	2 °C	1 °C	2 °C
10th June	3085.9	2627.1	2294.6	-14.9	-25.9
20th June	3776.6	3773.7	3544.1	-6.2	-6.2
30th June	3549.9	3601.7	2953.1	1.5	-16.8
10th July	3336.1	3110.1	3025.9	-6.8	-9.3

Table 118. Impact of elevated CO_2 (470 ppm) and 1°C & 2°C rise temperature on days to anthesis and maturity of rice crop

Planting window	Days to anthesis			Days to maturity		
	Control	470 ppm		Control	470 ppm	
		1 °C	2 °C		1 °C	2 °C
10th June	**66**	**63**	**60**	**104**	**98**	**93**
20th June	**70**	**66**	**63**	**110**	**104**	**98**
30th June	**72**	**68**	**65**	**115**	**106**	**100**
10th July	**75**	**71**	**68**	**120**	**113**	**106**

Table 119. Impact of elevated CO_2 (470 ppm) and 1°C & 2°C rise temperature on rice yield

Planting window	Grain yield (kg/ha)			Percent increase/decrease	
	Control	470 ppm		470 ppm	
		1 °C	2 °C	1 °C	2 °C
10th June	3085.9	2939.2	2612	-4.8	-15.4
20th June	3776.6	4075.8	3854.6	7.9	2.1
30th June	3549.9	3888.1	3217.5	9.5	-9.4
10th July	3336.1	3445.9	3325.1	3.3	0.3

Impact of rainfall reductions

The total rainfall received at Palampur from past 36 years (1974 – 2009) during SW monsoon (June to September) is 1810.7 mm. The rainfall during simulation year was 1456 mm during SW monsoon. The 10 % and 20 % reduction in rainfall showed reduction in the rice yield to the tune of 0.1 to 0.7 percent except 30th June transplanting which showed increase of yield by 0.7 percent under 10 % rf. Further increase in the reduction of 20 % rf reduced the crop yield 1.0 to 9.6 under all the transplanting windows when compared with normal conditions (Table 120). The results of impact of rainfall reduction on days to anthesis and maturity showed no significant change with control (Table 121).

Table 120. Impact of rainfall reduction of (-10 % & -20 %) on rice yield

Planting window	Grain yield (kg/ha)			Percent change	
	Control	-10 % rf	-20 % rf	-10 % rf	-20 % rf
10th June	3085.9	3075.8	2788.6	-0.3	-9.6
20th June	3776.6	3748.5	3743	-0.7	-1.0
30th June	3549.9	3574.3	3504.2	0.7	-1.3
10th July	3336.1	3334.2	3178.6	-0.1	-4.7

Table 121. Impact of rainfall reduction of (-10 % & -20 %) on days to anthesis and maturity of rice crop

Planting window	Days to anthesis			Days to maturity		
	Control	-10 % rf	-20 % rf	Control	-10 % rf	-20 % rf
10th June	66	66	66	104	104	104
20th June	70	70	70	110	110	110
30th June	72	72	72	115	115	115
10th July	75	75	74	120	120	120

Impact of 15 days dry spell on rice yield under rainfed conditions:

Under dry spell of 15 days during the month of August the yield of rice crop reduced in first two transplanting windows 10th and 20th June by 31 percent, when compared to without dry spell period. Whereas, there was an increase of 1 to 7 percent yield under 30th June and 10th July transplanting windows (Table 122).

Table 122. Impact of 15 days dry spell during August on rice yield under rainfed conditions

Planting window	Yield (q/ha)		Percent increase / decrease
	Without dry spell	Dry spell	
10th June	36.71	25.71	-30
20th June	37.76	25.77	-31.6
30th June	36.37	34.06	-6.8
10th July	35.44	34.44	-1

Impact of 15 days dry spell on rice yield under rainfed conditions and as adaptation one irrigation level

Under rainfed conditions with the dry spell of 15 days during the month of August and adaptation as one irrigation level the yield of rice showed increase of 42.8 to 46.5 percent in first two transplanting windows of 10th and 20th June whereas, the 30th June and 10th July transplanting reduced the yield to the tune of 6.3 to 19.1 percent (Table123)

Table 123. Impact of 15 days dry spell on rice yield under rainfed conditions under one irrigation level

Planting window	Grain yield (q/ha)		Percent increase / decrease
	Dry spell	Dry spell with one irrigation	
10th June	25.71	36.71	42.8
20th June	25.77	37.76	46.5
30th June	36.37	34.06	-6.3
10th July	34.44	27.76	-19.3

Wheat (*Rabi*)

Validation of crop model for late sown wheat crop under irrigated conditions

The wheat crop model was validated for Palampur region and the validated models were used for assessment of climate change impact under different situations. The data from 2001 to 2002 was used to validate the INFOCROP Model. Simulated and observed days to maturity, anthesis and yield for wheat crop in Palampur were compared. To asses the impact of elevated carbon dioxide and temperature and rainfall variability, the crop model was run for year 2001 and 2002. Results showed that observed days to anthesis and maturity for wheat crop at Palampur were more than that of simulated values (Table 124 – 126).

Table 124. Simulated and Observed days to maturity for wheat crop in Palampur

S.No.	Planting date	Simulated	Observed
1.	30 November, 2000-01	170	176
2.	15 December, 2000-01	157	164
3.	30 December, 2000-01	144	154
4.	30 November, 2001-02	165	179
5.	15 December, 2001-02	153	167
6.	30 December, 2001-02	136	155

RMSE = 12.50

Table 125. Simulated and Observed days to anthesis for wheat crop in Palampur

S.No	Planting date	Simulated	Observed
1.	30 November, 2000-01	134	137
2.	15 December, 2000-01	123	125
3.	30 December, 2000-01	114	116
4.	30 November, 2001-02	130	147
5.	15 December, 2001-02	118	133
6.	30 December, 2001-02	106	120

RMSE = 11.00

Table 126. Simulated and Observed yield for wheat crop under irrigated conditions in Palampur

S.No	Planting date	Simulated	Observed
1.	30 November, 2000-01	4895	4190
2.	15 December, 2000-01	4953	4836
3.	30 December, 2000-01	3636	4046
4.	30 November, 2001-02	4554	3983
5.	15 December, 2001-02	4406	4360
6.	30 December, 2001-02	3752	4045

RMSE = 426.77

Salient Findings:

Planting window under six irrigated levels

The late sown wheat crop under recommended package and practices were simulated under irrigated conditions at Palampur. The results revealed that 30th November sown to be the best planting window followed by 15th December. Whereas, the sowing done on 30th December resulted lowest yield (Table 127).

Table 127. Impact of planting windows on days to anthesis, maturity and grain yield of late sown wheat crop yield

Planting window	Days to anthesis	Days to maturity	Yield (kg/ha)
30th November	137	165	4307.1
15th December	126	151	3339
30th December	116	139	2103.5

Impact of elevated levels carbon dioxide levels

Elevated levels of carbon dioxide 420 ppm and 470 ppm simulated under irrigated conditions were compared with control 370 ppm indicated increase in the yield of wheat. The higher levels of carbon dioxide increased the yield under all the planting windows compared to control. The magnitude of increase under 50 ppm level resulted 3.6 to 4.0 percent whereas, under 100 ppm yield increased to the tune of 1.7 to 7.5 (Table 129). Compared to control crop took almost equal number of days in both 50 and 100 ppm increased carbon dioxide levels (Table 128).

Table 128. Impact of elevated CO_2 (420 ppm & 470 ppm) level on days to anthesis and maturity of late sown wheat crop

Planting window	Days to anthesis			Days to maturity		
	Control	420 ppm	470 ppm	Control	420 ppm	470 ppm
30th November	137	137	137	165	165	165
15th December	126	126	126	151	151	151
30th December	116	116	116	139	139	139

Table 129. Impact of elevated CO_2 (420 ppm & 470 ppm) level on of late sown wheat crop

Planting window	Grain yield (kg/ha)			Percent increase/decrease	
	Control	420 ppm	470 ppm	50 ppm	100 ppm
30th November	4307.1	4480.4	4381.5	4.0	1.7
15th December	3339.0	3468.8	3590.9	3.8	7.5
30th December	2103.5	2180.0	2244.5	3.6	6.7

Impact of elevated levels of temperature

Under irrigated conditions the increase in temperature of 1°C and 2°C also increased the yield in all the planting windows. The simulated yield with 1°C and 2°C rise in temperature were compared with no change in temperature under rainfed and six irrigated conditions. The temperature rise of 1°C and 2°C showed that increase in the yield to the tune 17.9 to 63.0 and 33.2 to 113.4 percent under all panting windows (Table 131). The 1°C rise in temperature caused 4 to 6 days advancement in maturity whereas, 2°C rise in temperature advanced the maturity by 7 to 8 days (Table 130).

Table 130. Impact of elevated 1°C and 2°C rise temperature on days to anthesis and maturity of late sown wheat crop

Planting window	Days to anthesis			Days to maturity		
	Control	1 °C	2 °C	Control	1 °C	2 °C
30th November	137	131	126	165	160	157
15th December	126	119	115	151	147	144
30th December	116	111	105	139	135	132

Table 131. Impact of elevated 1°C and 2°C rise temperature on late sown wheat crop

Planting window	Grain yield (kg/ha)			Percent increase/decrease	
	Control	1 °C	2 °C	1 °C	2 °C
30th November	4307.1	5078.8	5738.1	17.9	33.2
15th December	3339	4759.5	4966.1	42.5	48
30th December	2103.5	3428.6	4488.2	63.0	113.4

Impact of elevated temperature and carbon dioxide levels

The yield of wheat crop increased with rise in 1°C and 2°C temperature when coupled with the elevated carbon dioxide levels of 50 and 100 ppm over different dates of sowing. The 1°C and 2°C elevated levels of temperature coupled with 50 ppm level of carbon dioxide increased the yield by 23.0 to 69.7 % and 39.5 to 123.5 % (Table 132). Further increase of 100 ppm carbon dioxide also increased the yield by the tune of 27.9 to 76.1 % and 46.4 to 133 percent under 1°C and 2°C elevated levels of temperature, respectively (Table 133). The 1°C rise in temperature coupled with 50 ppm higher level of CO_2 advanced the maturity of the crop by 4 to 5 days whereas, 2°C rise in temperature coupled with 50 ppm CO_2 level advanced the maturity by 7 to 8 days (table 134). Whereas, further increase of carbon dioxide to 100 ppm CO_2 level showed similar number of days in advancing the maturity period (Table 135).

Table 132. Impact of elevated CO_2 (420 ppm) and 1°C & 2°C rise temperature on late sown wheat crop

Planting window	Grain yield (kg/ha)			Percent increase/decrease	
	Control	420 ppm		420 ppm	
		1 °C	2 °C	1 °C	2 °C
30th November	4307.1	5297.1	6012	23.0	39.5
15th December	3339	4973.2	5202.1	48	55.8
30th December	2103.5	3570.2	4700.8	69.7	123.5

Table 133. Impact of elevated CO_2 (470 ppm) and 1°C & 2°C rise temperature on late sown wheat crop

Planting window	Grain yield (kg/ha)			Percent increase/decrease	
	Control	470 ppm		470 ppm	
		1 °C	2 °C	1 °C	2 °C
30th Nov	4307.1	5508.2	6309.4	27.9	46.4
15th Dec	3339	5185.4	5431	55.2	62.6
30th Dec	2103.5	3705.3	4901.8	76.1	133

Table 134. Impact of elevated CO_2 (420 ppm) and 1°C & 2°C rise temperature on days to anthesis and maturity of late sown wheat crop

Planting window	Days to anthesis			Days to maturity		
	Control	420 ppm		Control	420 ppm	
		1 °C	2 °C		1 °C	2 °C
30th November	137	131	126	165	160	157
15th December	126	119	115	151	147	144
30th December	116	111	105	139	135	132

Table 135. Impact of elevated CO_2 (470 ppm) and 1°C & 2°C rise temperature on days to anthesis and maturity of late sown wheat crop

Planting window	Days to anthesis			Days to maturity		
	Control	420 ppm		Control	420 ppm	
		1 °C	2 °C		1 °C	2 °C
30th November	137	131	125	165	160	157
15th December	126	119	115	151	147	144
30th December	116	111	105	139	135	132

Objective : Demonstration studies for verifications of simulated adaptations for maize and wheat in Kangra and Chamba

To validate the simulated guided management for maize and mustard the field demonstrations on farmers' fields at Una, Kangra and Chamba with ECFs farmers for simulated maize planting widnows and Mustard crops laid out to verify the simulated adaptations *viz.,* Change of sowing windows. The 200sq mt area was taken for demonstrations.

Salient findings

Maize: The best simulated planting date for maize was 20th June under increased temperature of 1 and 2 ^{0}C under Dhaulakuan conditions (Based 1989-2008 data) and delay in sowing showed more impact of increased temperature. Based on the simulated adaptations, the demonstration on different sowing at Farmers field was laid out in Una districts represents similar elevation and climate of Dhaulakuan. The sowing done after 10-20 June showed 4.6 quintal /ha higher yield of maize compared to 3rd week of June sowing (Table 136).

Table 136. Details about the demonstration plots on maize

Name of Farmer	Maize (Var.KH-101)	Demonstration
	Date of sowing	Yield (q/ha)
Sowing between 10-20 June		
Sh Amar Chand,VPO Doggy Dehrian	19.6.09	30.0
Sh Rattan Singh,VPO Makrahan, Jawali	18.6.2009	24.0
Sh. Jeet Singh,VPO Sill,Jawalamukhi	13.6.09	42.0
Sh.Harmesh Singh VPO Sathkali	18.6.09	44
Sh. Panna Lal, Vill Lower Indora, Tehsil Amb Distt Una	11.6.09	34.0
	Mean	34.80
Sowing after 20 June		
Ajit Singh	2.7.2009	24
Puran Singh	1.7.2009	34.8
	Mean	29.4

Mustard : The simulated planting windows for mustard was November ,9 based on 20 years simulation under increased temperature and 1-3 irrigations conditions at Palampur region. Based on the simulated planting windows demonstration on farmers filed was laid out to verify the simulated adaptations. The yield of mustard crops was 62 kg /ha higher when crop was sown during 1-15 November compared to crops sown during October 20-30 October (Table 137).

Table 137. Details about the demonstration plots on mustard

Name of Farmer	Mustard (Var.HPN-3)	Demonstration
Sowing between 20 to 30 October,2009		
	Date of sowing	Yield (q/ha)
Sh Amar Chand,VPO Doggy Dehrian	27.10.09	11.20
Sh. Jeet Singh,,VPO Sill,Jawalamukhi	30.10.09	10.70
Sh. Panna Lal, Vill Lower Indora, Tehsil Amb Distt Una	16.10.09	11.0
Sh.Harmesh Singh VPO Sathkali	18.1009	9.90
	Mean	10.85
Sowing after 1- 15 November, 2009		
Sh Ajit Singh, Vill Dehri Tehsil Nurpur	11-1-09	10.80
Sh.Puran Chand, Vill. Rajour Po.Ranital	25.11.09	11.50
Sh Rattan Singh ,VPO Makrahan, Jawali	14.11.09	12.20
	Mean	11.50

Objective : Impact of climate change on Tea production under sub humid sub temperate climate of Himachal Pradesh

The productivity and quality (Terminal & Bud) data for 1981 to 2009 was collected from Department of Tea husbandry form 14 ha. area and productivity was calculated for different years. All the recommended packages and practices were followed similar in every year. The long term climate data was correlated with all weather parameters, viz Maximum Temperature, Minimum Temperature, Rainfall, Relative Humility, Sunshine & Evaporations and detrend analysis were carried out to assess the impact of climate change on tea production. The each monthly data was used the productivity & Tea quality data was correlated & detrended with each month weather parameter taking one week prior data for monthly average.

Tea Productivity: The productivity showed increasing in all the months from 1983 to 2009 from 14 hac. experimental area similarly two leaf and bud also followed similar trends.

The maximum temperature trends showed increase in temperature during plucking period the increase ranged from 0.3 to 4.1 ^{0}C past 27 years. The minimum temperature showed increasing March to May whereas June to October minimum temperature registered decrease .Rainfall trend showed decrease during tea plucking period. March average temperature was 20 ^{0}C and an increase of 4.1^{0}C was observed in past 27 years which showed positive sensitivity with maximum temperature. Similarly during mean temperature of August and September was 26.1 and 26.5^{0}C and an slight increase of 0.8 and 0.5 ^{0}C was observed .the maximum temperature during April and May showed 3^{0}C rise from the mean temperature of 24.7 and 29.0 ^{0}C. June month showed significant relation of maximum temperature. The rise beyond 30.5 ^{0}C causes significant reduction. The further rise in temperature will decrease the tea productivity during April, May, June July and October. The maximum temperature trends were showing decrease in temperature June to October. The further decease in temperature during April and June reduce the tea productivity.

Rainfall: rainfall Trends were showing decreasing trends except September months. The reduced rainfall was more than 50 % from the mean rainfall during March to May where as the remaining months showed 10-20 % decrease in rainfall. Hence rainfall decrease from March to May caused reduction in tea productivity.

Impact of Climate Change on Tea production & quality of Himachal Pradesh

Impact on Productivity:

Maximum Temperature: Maximum temperature showed the negative sensitivity with tea productivity in April, May, June, July and October months whereas March, August and September months showed positive sensitivity which reflected that the increase in maximum temperature caused decrease of green leaf productivity during April, June, July and October. The minimum temperature showed negative sensitivity with productivity during April and June months reflecting lowering of temperature caused decrease in productivity. The June month maximum temperature showed highly significant relation, one degree rise in average temperature of 30.5^0 C showed 11 percent reduction in the yield.

Rainfall: March to May rainfall showed negative sensitivity with Tea productivity whereas June to October months showed positive sensitivity. Increase in rainfall has less impact on productivity then decrease of rainfall from average of 69.1mm during June months. The further decrease of rainfall from 69.1 mm showed reduction in tea production during June month.

Evaporation and Humidity: Evaporation showed that negative sensitivity with productivity during April to July and October period of tea leaf plucking. Increase of evaporation showed more impact of reducing the yiled than increase of evaporation from mean monthly values. The correlation coefficients were negative during these months signifying that increase in evaporation caused reduction of yield.

RH: The relative humidity showed positive sensitivity with all months from April to October except March, August and September months.

Sunshine: The duration of sunshine from June to October were negatively correlated with productivity. The detrend analysis showed negative sensitivity with productivity during June, July , September and October The decrease of sunshine hours during these months impact less on yield than increase of the sunshine hours during these months.

Quality of Tea: The Two leaves and bud (T&B) percent yield was correlated with each weather parameters and sensitivity to parameter worked out.

Maximum Temperature: The maximum temperature showed significant negative correlation June & July months. The negativity sensitivity of maximum temperature with quality was observed during April, June, July and October which reflected more decrease of quality tea leaf with increase of temperature there from the average value.

Minimum Temperature: the minimum temperature showed negative correlation during June to August and October months. The sensitivity of minimum temperature was negative during April to June. The further decrease of average minimum temperature caused more reduction in quality.

Rainfall: The rainfall of June & September showed positive correlation with tea quality compared other months from April to October. The sensitivity analysis showed negative sensitivity during March to May & August months. The decrease of rainfall from average monthly rainfall during these months caused more yield with increase in rainfall.

Evaporation: The evaporation of April, May, July and October months showed negative correlations with quality. The sensitivity of tea quality with Evaporation showed negative sensitivity during April to July and October months.

Relative Humidity: The RH during March and May showed negative relation with quality, whereas sensitivity of RH was negative during August and September. The further decrease of mean monthly humidity of these months cause more reduction in quality than increase.

Sunshine: The correlations coefficients and sensitivity of sunshine showed negative relationship during June-July and September to October period.

Objective: Impact of climate change on water inflow of major rivers of Himachal Pradesh

The data for 1965 was collected from Bhakhra Beas Management Board Chandigarh and trends were worked for river discharge flow to assess the impact on river water resources.

Salient findings:

Water Resources and Reserves in Major River Basins of Himachal Pradesh

Himachal Pradesh has vast glacial reserves some of which contain huge amount of perpetual snow and ice. The total number of glaciers in Himachal Pradesh is estimated to be 2554 with reserve of 387.35 km^3 covering an area of 4160.58 km^2. The river network of Himachal Pradesh is very complex. Although there are only four major rivers i.e. Satluj, Beas, Ravi and Chenab, but these rivers have many tributaries and streams flowing in and out of them (Fig.165) These small rivulets besides serving a source of irrigation and drinking water also are abound with a variety of fish.

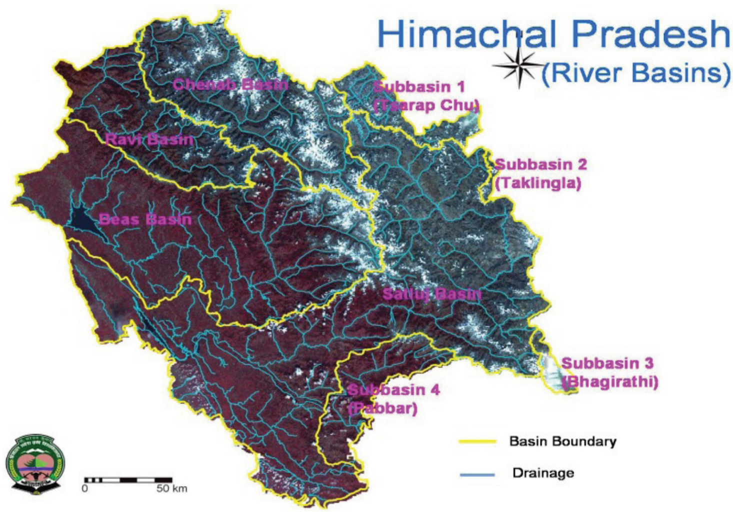


Fig. 165. River Basins and Drainage Lines (rivers) of Himachal Pradesh

Satluj River Basin : Sutlej is the longest and largest river traversing the Pradesh from east to west and plausibly, Sutlej river basin is largest among five basins of the State. It spreads over 30° 22'to 32° 42' N latitude and 76° to 79° E longitude horizontally. Eighty percent of its catchment is snow fed. The river finally joins at Bhakhra Nangal Dam.

Beas River Basin: The western part of Himachal Pradesh is occupied by the Beas river basin. It lies between 31°24' N - 32° 36' N latitude and 75° 36' E -77°.52' E longitude. The Beas river network comprises Parbati, Binwa, Neugal, Banganga, Gaj, Dehr, Chakki Kunal, Masch, and Khairan as main contributing rivers. The main Beas river flows from east to west.

Ravi River Basin: The Ravi river basin extends from 32º 13' N to 33º 03' N latitude to 75° 46' E to 77° 01' E longitude. It is the smallest of the four major river basins of Himachal Pradesh.

Chenab River Basin: The Chandra and the Bhaga rivers are the main drainage lines of Chenab basin. After their, confluence at Tandi in Lahaul Valley, their combined waters constitute the Chandrabhaga or the Chenab river. It has a catchment area of 61,000 sq km out of which 7,500 sq km lie in Himachal Pradesh. It is the longest river of Himachal Pradesh in terms of volume of waters. The river is fed by numerous glaciers distributed throughout.

The discharge data recorded for river Beas at Manali, gauge sites, Parvati at Parvati and for Satluj at Songtong located at Kinnaur in Sutlej catchment were analyzed for working out the trends of discharge flow of rivers. The trends were presented graphically for all the months. The inflow of Satluj River at Bhakhra was also analyzed to work out the change in water inflow of river Sutlej in past two decades

The Beas river water flow discharge at the gauge sites namely Manali (2200 m elevation) and Mandi (600 m elevation) were analyzed to see the elevation impact also. The data used was (1966 to 2005).

River Beas water flow Discharge (Manali Guage site)

Discharge Manali: The daily mean /normal discharge averaged over 56 years varied between 306.8 cusecs to 2356 cusecs in all the years. The peak daily average discharge for River Beas was 2356 during July month followed by 2305.9 during August. The average daily water flow discharge in Cusec for different months for the period of 1969 – 2009 (35 years) recorded at Manali gauge site for river Beas indicated significant decrease in all the months. The maximum decreasing trends in daily water flow discharge (cusec) from April to September ranged between -16.34 to 51.60 cusec per year. The maximum decrease of 1857.7 cusec in daily water flow discharge was observed during August followed by July (1770.2 cusec) since 1969. The magnitude of decrease in the rate of water flow discharge for winter months from October to March varied between -6.02 to -10.94 cusec. The lowest rate of decrease was observed during January which is the coldest month in the catchment area. The flow pattern behaves like normal curve during different months. The gauge site at Manali is located at 2200 m above mean sea level and the river is exclusively fed by snow and glaciers from the higher elevation at the guage site.

Discharge Parvati: The average daily water discharge for different months for the period 1968-2005 (37 years) recorded for river Parvati indicated significant decrease in all the months. The average daily water flow discharge pattern behaves like normal curve during different months. The highest and lowest average daily water flow discharge was observed during July (7482 cusecs) and January (647 cusecs) respectively. The maximum decrease of 7482 cusecs in daily water flow discharge was observed during July followed by August (7006 cusecs). Since 1968 in last 37 years data the magnitude of decreasing trends for winter months October to March varies between -9.423 to -17.446 cusecs. The lowest rate of decrease was observed during March (-9.423 cusecs).

River Satluj: Mean total monthly discharge of river Satluj recorded at Songtong in district Kinnaur for the period of 1993 to 2006 indicated decreasing trends in all the months except May. The decreasing rate was highest during August (464.8 cusecs) followed by June 469.8 cusecs per year. The highest average total monthly discharge of river Satluj varied between 1844.9 to 20869.2 cusecs. The peak discharge of 20869 was observed during August followed by June 19472 (cusecs).

Satluj inflow in Bhakhra Dam: The inflow of Satluj river in Bhakhra is the final drainage outlet of the Satluj basin. The inflow data for the period of 1984 to 2003-04 revealed a decreasing trend in annual inflow (million acres feet) where as the average inflow of 20 years was 11.74 million acre feet.

Objective: Validation of Local traditional knowledge of climate and weather and relations crop productivity

Local Stories in district Kangra Himachal Pradesh

There is adage/ aphorism in Plampur –Kangra valley of Himachal regarding the good or bad monsoon. "VAREHEA TEER TO HUA PHAKIR means if there is intense heat continues during second and third week of June(7th to 24rth June) then it is indicative of good SW-monsoon during that year and if rains occur during that period then below normal SW-monsoon rains are expected. If first 10-15 days of *Jeth* (June) month are very hot, good rainfall is predicted during ensuing rainy season.

Salient findings: SW monsoon rainfall and rainfall during the teer period showed decreasing trends in last 36 years weather data at Palampur. The mean minimum temperature showed decreasing trends during teer period in the region which is the reason for the decreasing trend in rainfall during SW monsoon rainfall as per farmer's perceptions. The minimum temperature during June also showed decreasing trends in Palampur region.

Validation of local knowledge

The validation of local knowledge on SW monsoon rainfall distribution was done. The maximum temperature during 7 to 24 June showed the positive trends with amount and distribution of SW-monsoon. At Palampur, when teer period temperature showed increase, the rainfall distribution i.e. dry days viz. 1-day, 2-days , 3-consective days.4-consective days and 5-consective dry days during July to September showed decrease in last 36 years data. The July and September months showed negative correlations with dry days. Whereas August showed positive correlations signifying that frequency of dry days showed increase with increase in maximum temperature during teer period. The amount of SW monsoon showed positive correlation with temperature during teer period. Higher the temperature during teer period higher is the amount of rainfall. The local knowledge was also verified for the Dhalakuan and Bajuara region but showed inconsistent results. The perceptions of the farmers about local knowledge correspond true with weather data of past 36 years for Palampur region.

Objective : Climate literacy among stakeholders

One day awareness programme on Climate literacy to Farmers were carried out in three places at CSKHPKV, Palampur, rice and wheat research Station Malan and KVK Kullu.

Seminar on Climate, Weather and Farmers:

The 152 farmers, (men and women), four media persons, four Agriculture department officers and 15 faculty from four districts Una, Chamba, Hamirpur and Kangra participated in the one day seminar on "Climate, Weather and Farmers" held in seminar hall, Directorate of Extension Education of CSK

HPKV, Palampur on dated 17.03.10. Climate change, its indicators and impact of climate change was displayed through the poster s and lecture on different aspects were delivered. In addition to this application of weather forecasts to reduce the climate vulnerability was also discussed.

Two one day awareness programme at Rice and wheat research station Malan, Kangra where 48 farmers participated and at KVK Kullu 36 farmers attended the one day awareness programme on climate on 5.4. 2010 at Malan and KVK, Kullu on 12.4.2010.

The precise survey schedule was prepared and distributed to the farmers. The farmers' perceptions were worked out on the percent response of the farmers to particularly query. More than 84 percent farmers perceived that television is the best media for climate and weather information. With regard to climate change majority of farmers responded that they have changed their cropping patterns and sowing dates. The planting dates are changed every year depending upon the sowing rains during *rabi* and *kharif* season. The delayed maize sowing during second week of June is beneficial these days. All the farmers showed their willingness for such seminars.

Project Staff

Co-Investigators

Coordinating unit: Indian Agricultural Research Institute, New Delhi

- **National Coordinator : Dr. P.K. Aggarwal**
  Designation : ICAR National Professor
- Name : Dr.S.Naresh Kumar
  Designation : Senior Scientist, Div Environmental Sciences, IARI
- Name : Dr.H. Pathak
  Designation : Senior Scientist, Div Environmental Sciences, IARI

Indian Agricultural Research Institute, New Delhi

- **Name : Dr. S.D. Singh, Principal Investigator**
  Designation : Principal Scientist, Division of Environmental Sciences
- Name : Dr. Santha Nagarajan
  Designation : Principal Scientist, Nuclear Research Laboratory
- Name : Dr. Anitha Choudhary
  Designation : Senior Scientist, Division of Environmental Sciences
- Name : Dr. Madan Pal
  Designation : Senior Scientist, Division of Plant Physiology
- Name : Dr. Subash Chandra
  Designation : Senior Scientist, Entomology
- Name : Dr. Anjali Anand
  Designation : Senior Scientist, Nuclear Research Laboratory
- Name : Dr. Arti Bhatia
  Designation : Senior Scientist, Division of Environmental Sciences
- Name : Dr. Niveta Jain
  Designation : Senior Scientist, Division of Environmental Sciences
- Name : Dr. Bidisha Benerjee
  Designation : Scientist Sr.Scale, Division of Environmental Sciences

Central Research Institute for Dryland Agriculture, Hyderabad

- **Name : Dr. G.G.S.N. Rao, Principal Investigator**
  Designation : PC, Agromet

- Name : Dr. M. Vanaja
  Designation : Principal Scientist (Plant Physiology)

- Name : Dr. M. Srinivasa Rao
  Designation : Senior Scientist (Entomology)

- Name : Dr. A.V.M. Subba Rao
  Designation : Scientist (SS) (Agrometeorology)

- Name : Dr. V.U.M. Rao
  Designation : Principal Scientist (Agrometeorology)

- Name : Dr. S. Desai
  Designation : Principal Scientist (Plant Pathology)

- Name : Dr. Ch Srinivasa Rao
  Designation : Principal Scientist (Soil Science)

- Name : Dr. K.V Rao
  Designation : Principal Scientist (S&SWC)

Central Plantation Crop Research Institute, Kasaragod

- **Name : Dr. (Mrs.) K.V. KASTURI BAI, Principal Investigator**
  Designation : HD, PB&PHT

- Name : Dr.D.Balasimha
  Designation : Principal Scientist

- Name : Dr.S.Naresh Kumar (from August, 2008)
  Designation : Senior Scientist, Div Environmental Sciences, IARI

Indian Institute of Horticultural Research Institute, Bangalore

- **Name : Dr. N. K. Srinivasa Rao, Principal Investigator**
  Designation : Principal Scientist

- Name : Dr. R.M. Bhatt
  Designation : Principal Scientist

- Name : Dr. R.H. Laxman
  Designation : Senior Scientist

- Name : Dr. K.S. Shivashankara
  Designation : Senior Scientist

Central Soil and water Conservation Research and training Institute, Dehradun

- **Name : Er. K.P. Tripati, Principal Investigator**
  Designation : Principal Scientist, (Soil & WCE)

- Name : Dr. D.R.Sena
  Designation : Scientist Sr.Sclale, (S &WCE) at Vasad, Gujarat
- Name : Dr. A.K.Viswakarma
  Designation :

- Name : Dr. Gopal Kumar
  Designation : Senior Scientist ,(Agronomy) at Vasad, Gujarat

- Name : Er. Sridhara Patra
  Designation : Scientist ,(S& WCE) at Deharadun

ICAR Research Complex for Eastern Region, Patna

- **Name : Dr. Abdul Haris, Principal Investigator**
  Designation : Senior Scientist

- Name : Dr. Abdul Islam
  Designation : Senior Scientist

- Name : Dr. R. Elanchezhian
  Designation : Senior Scientist

National Dairy Research Institute, Karnal

- **Name : Dr. R. C. Upadhyay, Principal Investigator**
  Designation : Principal Scientist (Animal Physiology)

- Name : Dr. Sohan Vir Singh
  Designation : Senior Scientist, (Animal Physiology), DCP Division

- Name : Dr. Ashutosh
  Designation : Senior Scientist (Animal Physiology), DCP Division

- Name : Dr Harjeet Kaur
  Designation : Principal Scientist Scientist,, DCN Division

- Name : Dr A.S.Chandel
  Designation : Principal Scientist, DES&M Division

Central Marine Fisheries Research Institute, Cochin

- **Name : Dr. E. Vivekanandan, Principal Investigator**
  Designation : Principal Scientist & Head of Division
  Demersal Fisheries Division, CMFRI, Cochin

- Name : Dr. N.G.K.Pillai & Head of Division
  Designation : Principal Scientist, Pelagic Fisheries Division, CMFRI,Cochin

- Name : Dr. SunilKumar Mohammed
  Designation : Head, Molluscan Fisheries Division, CMFRI, Cochin
- Name : Dr. Mohammad Khasim
  Designation : Madras R.C of CMFRI, Chennai
- Name : Dr. V.V.Singh, Principal scientist
  Designation : Mumbai Research Centre of CMFRI, Mumbai
- Name : Dr. Jayasankar, Senior scientist
  Designation : Fishery Resources Assessment Division, CMFRI, Cochin
- Name : Sri. K.Vijayakumarn, Scientist(SG)
  Designation : Fisherie Environment & Management Division
  Mangalore R.C. of CMFRI, Mangalore
- Name : Dr. R. Sathiadhas
  Designation : Principal Scientist & Head, Socioeconomics &
  Technology Transfer Division, CMFRI, Cochin
- Name : Dr. Ramachandran
  Designation : Principal Scientist & Head, Socioeconomics &
  Technology Transfer Division, CMFRI, Cochin
- Name : Dr. Joe Kizhakudan
  Designation : Madras R.C of CMFRI, Chennai

Central Inland Fisheries Research Institute, Barrackpore

- **Name : Dr. Manas Kumar Das, Principal Investigator**
  Designation : Principal Scientist & Head
- Name : Dr. Prasanta Kumar Saha
  Designation : Principal Scientist
- Name : Mr. S.K.Sahu
  Designation :

Tamil Nadu Agricultural University, Coimbatore

- **Name : Dr. C.R. Ranganathan, Principal Investigator**
  Designation : Professor, (Mathematics) & Dr. N. Ajjan, Director (CARDS)
- Name : Dr. K.R. Ashok
  Designation : Professor (Agri. Economics)
- Name : Dr. Geethalakshmi
  Designation : Professor & Head (Agro Climate Research Centre)

- Name : Dr. Dr. A. Lakshmanan
  Designation : Associate Professor (Agri. Microbiology)

Bidhan Chandra Krishi Vidyapeeth, Kalyani

- **Name : Dr. Saon Banerjee, Principal Investigator**
  Designation : Assoc. Prof

- Name : Dr. S.A.Khan
  Designation : Professor

- Name : Dr. Asis Mukherjee
  Designation :

- Name : Dr. L.Das
  Designation :

National Bureau of Soil Survey and Land Use Planning, Nagpur

- **Name : Dr. Bhattacharyya, Principal Investigator**
  Designation : Principal Scientist, Division of Soil Resource Studies

- Name : Dr. P.Chandan
  Designation :

- Name : Dr. M.V.Venugopalan
  Designation

- Name : Dr. D.K.Pal
  Designation

- Name : Dr. S.K. Ray
  Designation

- Name : Dr. (Mrs) C. Mandal
  Designation

- Name : Dr. D.Sarkar
  Designation

- Name : Dr. P.Tiwary
  Designation

Central Potato Research Institute, Shimla

- **Name : Dr. J.P.Singh, Principal Investigator**
  Designation : Principal Scientist

- Name : Dr. PM Govindakrishan
  Designation :

- Name : Dr. SS Lal
  Designation

- Name : Dr. V.K.Dua
  Designation

- Name : Manoj Kumar
  Designation

- Name : S.P.Singh
  Designation

- Name : Shashi Rawat
  Designation

National Research Centre for Agroforestry, Jhansi

- **Name : Dr. Ram Newaj,Principal Investigator**
  Designation : Principal Scientist, Agronomy

- Name : Dr. Badre Alam
  Designation : Senior Scientist (Plant Physiology)

- Name : Dr. A.K.Handa
  Designation : Principal Scientist (Forestry)

- Name : Dr. Ajit
  Designation : Senior Scientist (Statistics)

- Name : Dr. Rajenrda Prasad
  Designation : Principal Scientist (Soil Science)

- Name : Dr. Ramesh Singh
  Designation : Senior Scientist (SWCE)

Regional Station, Central Soil Salinity Research Institute, Lucknow

- **Name : Dr. V.K.Mishra, Principal Investigator**
  Designation : Principal Scientist, Soil Physics

- Name : Dr. Y.P.Singh
  Designation :

- Name : Dr. D.K.Sharma
  Designation :

- Name : Dr. A.K.Nayak
  Designation :

- Name : Dr. T.Damodaran
  Designation :

ICAR Research Complex for NEH Region, Barapani

- **Name : Dr. Anup Das, Principal Investigator**
  Designation : Senior Scientist, Agronomy

- Name : Dr. B U Choudhury
  Designation : Scientist

- Name : Dr. D P Patel
  Designation : Scientist

Project Directorate on Poultry, Hyderabad

- **Name : Dr.R.M.R.Reddy, Principal Investigator**
  Designation : Senior Scientist

- Name : Dr S.V.Rama Rao
  Designation : Principal Scientist

- Name : Dr U. Raj Kumar
  Designation : Senior Scientist

- Name : Dr M.Shanmugam
  Designation : Scientist

Tocklai Experimental Station, Tea Research Association, Tocklai, Jorhat

- **Name : Dr.R.M.Bhagat, Principal Investigator**
  Designation : Head, Production Division & Consultant

- Name : Dr. T.S.Burman
  Designation :

- Name : Dr. I.K.Phukan
  Designation

- Name : Dr. P.Tamuly
  Designation

Department of Agricultural Meteorology, B.A. College of Agriculture, Anand Agricultural University, Anand

- **Name : Dr. H. R. Patel, Principal Investigator**
  Designation : Assoc. Prof. (Agri. Met.)

- Name : Dr. Vyas Pandey
  Designation : Scientist

- Name : Prof. M.M. Lunagaria
  Designation : Professor

- Name : Prof. B. I. Karande
  Designation : Professor

Directorate of Soybean Research, Indore

- **Name** : Dr. V.S. Bhatia
  Designation : Principal Scientist (Crop Physiology)

Indian Institute of Sugarcane Research, Lucknow

- **Name : Dr. Arun K. Srivastava, Principal Investigator**
  Designation : Principal Scientist (Agmet)

- Name : Dr. A.K. Srivastava
  Designation : Principal Scientist (Plant Physiology)

- Name : Dr. S.N. Singh
  Designation : Senior Scientist (Agronomy)

Punjab Agricultural University, Ludhiana

- **Name : Dr. Prabhjyot Kaur Sidhu, Principal Investigator**
  Designation : Agrometeorologist, Dept of Agricultural Meteorology

- Name : Dr. Harpreet Singh
  Designation : Assistant Professor, Dept of Agricultural Meteorology

- Name : Dr. Kamal Vatta
  Designation : Research Officer, Dept.of Economics

CSK Himachal Pradesh Agriculture University, Palampur

- **Name : Dr. Dr Ranbir Singh Rana, Principal Investigator**
  Designation : Scientist (Agronomy)

- Name : Mr. Vaibhav Kalia
  Designation :

- Name : Dr. Sanjay Sharma
  Designation :

- Name : Dr. Sharda Singh
  Designation :

Research Associates and Senior Research Fellows

Indian Agricultural Research Institute, New Delhi (Coordinating center)

Name	From (date)	Till (date)
Mrs. D.N. Swarupa Rani	01.04.2008	To date
Dr. Rani Saxena	14.07.2009	To date

Indian Agricultural Research Institute, New Delhi

Name	From (date)	Till (date)
Dr. Praveen Kumar Sharma (RA)	14.05.2008	06.03.2009
Mr. Vinod Kumar (RA)	08.05.2008	31.03.2009
Ms. Shilpi Mishra (SRF)	12.10.2007	31.03.2009
Ms. S. Kalpana (SRF)	08.10.2007	31.03.2009
Dr. Vinay Kumar Singh (SRF)	15.11.2007	31.03.2009
Dr. Sunil Kum. Pandey (SRF)	11.02.2008	31.03.2009
Mr. Uttam Kumar (SRF)	08.05.2008	31.03.2009
Ms. Jyoti Jha (SRF)	23.09.2008	31.03.2009

Central Research Institute for Dryland Agriculture, Hyderabad

Name	From (date)	Till (date)
Mr. T. Satyanarayana (RA)	01.07.2008	Continuing
Mr. V. Ravi Kumar (SRF)	01.12.2008	Continuing
Mr. Abdul Razak (SRF)	18.01.2008	Continuing
Ms. D. Mani Manjari (SRF)	24.08.2009	Continuing
Ms. Mamta Joshi (SRF)	01.02.2010	Continuing
Mr. R. Prakash Naik (SRF)	01.02.2010	Continuing

Indian Institute of Horticultural Research, Bangalore

Name	From (date)	Till (date)
Ms. G.M. Ashwini(SRF)	15.12.2005	Resigned on 27.01.2010
Ms.G.A Geetha	18.02.2008	Continuing
Ms.H.Mamatha	26.07.2009	Continuing
Mrs. Srilakshmi	05.03.2010	Continuing

Central Soil and Water Conservation Research and Training Institute, Dehradun

Name	From (date)	Till (date)
Mr. Pravesh Saklani (SRF)	05.03.08	Till date

Central Plantation Crops Research Institute, Kasaragod

Name	From (date)	Till (date)
Mr. V.S. John Sunoj (SRF)	6.7.2007	Continuing
Mr. K.S. Murali Krishna (SRF)	9.7.2007	Continuing

ICAR Research Complex for Eastern Region, Patna

Name	From (date)	Till (date)
Ms. Vandana Chhabra	12.07.2005	Continuing
Ms. Anamika	09.12.2005	Continuing
Mr. Sandeep Biswas	11.09.2007	Continuing

National Dairy Research Institute, Karnal

Name	From (Date)	Till (Date)
Dr(Ms) Rita Rani	11.09.2008	Continuing
Ms Moloya Gohain	20.08.2008	31.07.2009
Ms Nitika Rani	21.01.2008	28.02.2009
Ms Syma Ashraf	08.09.2009	Continuing
Mr. Anil Kumar	08.01.2010	Continuing

Central Marine Fisheries Research Institute, Cochin

Name	From (date)	Till (date)
Mr. B. Jasper	25.06.2007	Continuing
Ms. U. Manjusha	25.06.2007	Continuing
Ms. R. Remya	23.07.2007	Continuing
Mr. Poonam Ashok Khandagale	26.09.2007	Continuing
Mr. T.V. Ambrose	08.08.2008	Continuing
Mr. Sony Paul	31.10.2009	Continuing

Central Inland Fisheries Research Institute, Barrackpore

Name	From (date)	Till (date)
Mr. Pankaj Kumar Srivastava (SRF)	05.01.2005	Continuing
Mr. Sumanto Dey (SRF)	10.01.2005	Continuing
Md. Liakat Mondal (SRF)	07.09.2007	Continuing

Central Potato Research Institute, Shimla

Name	From (date)	Till (date)
-	-	-

Tamil Nadu Agricultural University, Coimbatore

Name	From (date)	Till (date)
Mr. S. Govindaraj (SRF)	20.06.2007	Continuing
Mr. M. Rajkumar	01.03.2010	Continuing
Mr. L. Guruswamy (SRF)	04.07.2008	Continuing
Mr. Periyasamy (SRF)	23.01.2009	Resigned on 20.08.09
Mr. S. Senthilnathan (RA)	11.03.2007	Resigned on 29.12.09
Ms. J. Kavithamary (SRF)	18.01.2010	Continuing
Ms. N. Srimeena (SRF)	11.01.2010	Continuing
Ms. G.V. Nandini (JRF)	16.09.2009	Continuing

AICRP on Agrometeorology, Directorate of Research, BCKV, Kalyani

Name	From (date)	Till (date)
Mr. Barnali Saikia	07.12.2009	Continuing
Ms. Apurba Lal Mukharjee	04.03.2010	Continuing

National Bureau of Soil Survey and Land Use Planning, Nagpur

Name	From (date)	Till (date)
Mr. Ankush M. Nimje	07.07.2009	Continuing
Ms. Dipanwita Das Gupta	23.10.2009	Continuing
Ms. Dipalee D. Balbuddhe	01.04.2010	Continuing

National Research Centre for Agroforestry, Jhansi

Name	From (date)	Till (date)
Mr. Iqubal Singh (SRF)	08.09.2009	Continuing
Mr. Anil Kumar (SRF)	07.09.2009	Continuing

Central Soil Salinity Research Institute, Regional Research Station, Lucknow

Name	From (date)	Till (date)
Mr. Shafali Srivastva (RA)	21.11.2009	Continuing
Mr. Mohd. Shahabuddin (SRF)	17.08.2009	Continuing

ICAR Research Complex for NEH Region, Meghalaya

Name	From (date)	Till (date)
Mr. Enboklang Kharkrang	24.10.2009	Resigned on 14.04.2010
Mr. Amethyst Slong	26.10.2009	Continuing
Smt. Manju Rani Rajbonshi	10.05.2010	Continuing

Project Directorate on Poultry, Hyderabad

Name	From (date)	Till (date)
Mrs K Radhika (RA)	17.11.2009	Continuing
Mr. G Jagadeeswara Rao (SRF)	01.12.2009	Resigned on 31.03.2010
Mr. M Narasimha Rao	20.04.2010	Continuing

Tocklai Experimental Station, Jorhat, Assam

Name	From (date)	Till (date)
Er. Rupanjali Deb Baruah (RA)	12.06.2009	Continuing
Mr. Khanin Pathak (SRF)	01.07.2009	Continuing
Mr. Chimpi Sarmah (SRF)	01.07.2009	Continuing

Department of Agricultural Meteorology, B.A. College of Agriculture, Anand

Name	From (date)	Till (date)
Mr. Ashit Vinaykant Shah	10.12.2009	Continuing
Mr. Sheo Bardan Yadav	25.09.2009	Continuing

Directorate of Soyabean Research, Indore

Name	From (date)	Till (date)
Ms. Kancham Jumrani	17.08.2009	Continuing
Ms. Sita Jamra	03.08.2009	Continuing

Punjab Agricultural University, Ludhiana, Punjab

Name	From (date)	Till (date)
Mr. Amrinder Singh	August 2009	Continuing

CSK Himachal Pradesh Agriculture University, Palampur

Name	From (date)	Till (date)
Dr. Rohit Sharma (RA)	03.07.2009	Continuing
Mrs. Vasudha	23.09.2009	Continuing

BUDGET

Indian Agricultural Research Institute, New Delhi

Budget allocation and expenditure: (ending by March, 2010)

Centre	TA	RC	Contractual service	Work-shop	POL	Total RC	NRC	Total (7+8+9)
1	2	3	4	5	6	7	8	9
IARI, N. Delhi	1.00	6.00	15.00	0.00	0.10	22.00	0.00	22.00

Central Research Institute for Dryland Agriculture, Hyderabad

Budget allocation (In Lakhs) for this year 2009-10:

TA	OTA	RC	Contractu-al services	Work-shop	POL	Total RC (1+2+3+4+5+6)	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
1.00	-	6.00	14.00	1.00	0.20	22.20	-	-	22.20

Total Amount Spent: (April, 09 to March, 10): Rs. 21.29 lakh

TA	OTA	RC	Con-tractual services	Work-shop	POL	Total RC (1+2+3+4+5+6)	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
11079	-	267239	-378441	49289	20000	68358	762000	-	830358

Central Plantation Crops Research Institute, Kasaragod

Budget allocation (In Lakhs) for this year (ending by March, 2010):

TA	OTA	RC	Con-tractual services	Work-shop	POL	Total RC (1+2+3+4+5+6	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.75	0	2.00	4.00	0	0.00	6.75	0.00	0	6.75

Total Amount Spent: (April, 09 to March, 10) in Rs: 6, 10,591

Opening balance as on 1.4.2009 in Rs: 15, 53,921

TA	OTA	RC	Con-tractual services	Work-shop	POL	Total RC (1+2+3+4+5+6	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
31,818	0	259237	319536	0	0	610519	0	0	610519

Balance amount as on 31st March, 2010 in Rs: 1618330.0

(Provisional, need to checked by the accounts section)

Indian Institute of Horticultural Research, Bangalore

Budget allocation (In Lakhs) for this year (ending by March, 2010):

TA	OTA	RC	Con-tractual services	Work shop	POL	Total RC (1+2+3+ 4+5+6	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.75	-	2.00	6.00	-	0.20	8.95	-	-	8.95

Total Amount Spent: (April,08 to March, 09): Rs. 16,73320/

(Includes amount spent on NRC-Revalidated Amount)

Balance amount as on 31st March, 2009. : Rs. -111574/

Total amount spent in 2008-09

TA	OTA	RC	Con-tractual services	Work shop	POL	Total RC (1+2+3+ 4+5+6	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
81912	-	333667	588034	-	0.20	-	649709	-	16733620

Central Soil and Water Conservation Research and Training Institute, Dehradun

Budget allocation and amount received (Rs. in Lakhs) for this year (ending by March, 2010)

TA	RC	Contractual services	Work shop	POL	Total R.C.	NRC	Total
0.75	1.00	5.02	0.00	0.20	6.97	3.00 (Revalidation)	6.97

Total Amount Spent: (April, 09 to March, 10): (Rs. in Lakhs)

Traveling Allowances	RC	Contractual services	Work shop	POL	Total R.C.	NRC	Total
0.00	0.19	1.66	0.00	0.00	1.85	2.52	1.85

Balance amount as on 31st March, 2010.

Traveling Allowances	RC	Contractual services	Work shop	POL	Total R.C.	NRC	Total
0.75	0.81	3.36	0.00	0.20	5.12	0.48	5.12

ICAR Research Complex for Eastern Region, Patna

Budget allocation (in Lakhs) for this year (ending by March 2010):

TA	OTA	RC	Contractual services	Work-shop	POL	Total RC (1+2+3+4+5+6	NRC	Institutional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.75	0.00	2.00	6.96	0.00	0.20	9.91	0.00*	0.00	9.91

*Rupees 5.00 lakhs was revalidated from the allocated NRC grant for the year2007-08 and 2008-09

Opening balance as on 1st April 2009: Rs. 15.1616 lakhs

Total Amount Spent in lakhs: (April, 09 to March, 10): Rs. 8.21350

*Rs. 2.0274 lakhs was spent from revalidated NRC grants of previous year

Total amount spent including revalidated NRC: Rs. 10.2409 lakhs

TA	OTA	RC	Contractual services	Work-shop	POL	Total RC (1+2+3+4+5+6	NRC	Institutional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.60249	0.00	1.91298	5.69803	0.00	0.00	8.21350	0.00	0.00	8.21350

Amount received during 2009-10: Rs. 3.78 lakhs

Balance amount in hand as on 1st April, 2010: Rs. 8.7007 lakhs

National Dairy Research Institute, Karnal

Budget allocation (2009-2010)

Pay and Allowances	TA	Contingencies	Contractual Services	Work shop	Equipments	Vehicle / POL	Total
-	29,000	1,14,000	2,66,000	-	2,67,000	8,000	6,84,000

Total Amount spent (2009-10)

Pay and Allowances	TA	Contingencies	Contractual Services	Work shop	Equipments	Vehicle / POL	Total
-	65,401	82,112	3,52,656	-	-	-	5,00,169

Central Marine Fisheries Research Institute, Cochin

Budget allocation for 2008-09(in lakhs)

Amount released (April, 09 to March, 10): Rs 8,53,000

Total Amount Spent (April,09 to March, 10): Rs. 11,89,706

TA	OTA	RC	Con-tractual services	Work shop	POL	Total RC (1+2+3+ 4+5+6	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.75	0	4.00	11.20	0	0.00	16.15	0.00	0.00	16.15

Balance amount as on 31st March, 2010 (including unspent balance for the year 2008 – 09)

TA	OTA	RC	Contra-ctual services	Work-shop	POL	Total RC (1+2+3+ 4+5+6	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
18733	0	181028	118932	0	20000	338693	1200000	0.00	1538693

Central Inland Fisheries Research Institute, Barrackpore

Budget allocation (In Lakhs) for this year (ending by March, 2010)

TA	OTA	RC	Cotra-ctual services	Work-shop	POL	Total RC (1+2+3+ 4+5+6	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.75	-	3.00	5.00	-	0.20	8.95	-	-	8.95

Balance amount as on 31st March, 2010

TA	OTA	RC	Contra-ctual services	Work shop	POL	Total RC (1+2+3+ 4+5+6	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
51,241	-	55,357	830440	-	-	937038	-	-	937038

Tamil Nadu Agricultural University, Coimbatore

Budget allocation (In Lakhs) for this year (ending by March 2010)

TA	OTA	RC	Con-tractual services	Work-shop	POL	Total RC (1+2+3+4+5+6)	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
1.00	-	4.00	12.00	-	0.20	17.20	-	-	-
According to approval revalidation of unspent NRC grant available with our centre which was released during 2007-08 and 2008-09 under NPCC							5.00	-	22.20

Total amount spent (April 09 to March 2010) = 14,56,831.00

Closing balance as on: 31-03-2009 = 17, 64,994.00

Closing balance as on: 31-03-2010 = 11, 03,163.00

Expenditure for this year (ending by March 2010)

TA	OTA	RC	Con-tractual services	Work-shop	POL	Total RC (1+2+3+4+5+6)	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
31,133	-	3,82,617	5,77,535	-	-	9,91,285	4,65,546	-	14,56,831

AICRP on Agrometeorology, Directorate of Research, BCKV, Kalyani

Budget allocation (In Lakhs) for this year (ending by March, 2008):

TA	OTA	RC	Con-tractual services	Work shop	POL	Total RC (1+2+3+4+5+6)	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.5	0.0	1.00	3.40	0.00	0.00	4.90	0.00	0.00	4.90

Total Amount Spent: (December, 09 to March, 10): Rs. 94,801/- *

Balance amount as on 31st March, 2010

Expenditure statement (in Rs.)

TA	OTA	RC	Con-tractual services	Work shop	POL	Total RC (1+2+3+4+5+6	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
18,274*	0	20,011	56,560	0	0	94,801	0	0	94,801

(* Tentative as all submitted bill are yet to be passed from Comptrollers' Section)

National Bureau of Soil Survey and Land Use Planning, (NBSSLUP) Nagpur

Budget allocation (In Lakhs) for this year (ending by March, 2010)*

TA	OTA	RC	Con-tractual service	Work-shop	POL	Total RC (1+2+3+4+5+6)	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.65	0.00	2.00	6.96	0.00	0.10	9.71	0.00	0.00	9.71

Total Amount Spent: (April, 09 to March, 10) Rs.*

TA	OTA	RC	Con-tractual service	Work-shop	POL	Total RC (1+2+3+4+5+6)	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
51,371	0.00	47,452.4	2,46,584	0.00	0.00	3,45,407	45,399	0.00	3,90,806

* This is from our record. The financial report will be sent separately.

Central Potato Research Institute, Shimla

Budget allocation (In Lakhs) for this year (ending by March, 2010)

TA	OTA	RC	Con-tractual services	Work-shop	POL	Total RC (1+2+3+4+5+6	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.50	0.00	2.00	5.16	0.00	0.10	7.76	0.00	0.00	7.76

Total Amount Spent: (April,09 to March, 10): Rs. 156231

Balance amount as on 31st March, 2010: Rs. 219769

TA	OTA	RC	Con-tractual services	Work shop	POL	Total RC (1+2+3+4+5+6	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.00	0.00	1.56	0.00	0.0	0.00	1.56	0.00	0.00	1.56

National Research Centre for Agroforestry, Jhansi

Budget allocation (in Rupees) for this year (ending by March, 2010)

TA	OTA	RC	Con-tractual services	Work-shop	POL	Total RC (1+2+3+4+5+6	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
50,000	0.0	1,00,000	3,77,000	0.0	0.0	5,27,000	0.0	0.0	5,27,000

Total Amount Spent: (April,09 to March, 10): Rs. 2,74,600

Balance amount as on 31st March, 2010. (Amount in Rs.)

TA	OTA	RC	Con-tractual services	Work-shop	POL	Total RC (1+2+3+4+5+6	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
14,936	0.0	1,104	2,36,360	0.0	0.0	2,52,400	0.0	0.0	2,52,400

Central Soil Salinity Research Institute, Lucknow

Budget allocation (In Lakhs) for the year 2009-10

TA	OTA	RC	Con-tractual services	Work-shop	POL	Total RC (1+2+3+4+5+6	NRC	Institu-tional charges	Total (7+8+9)	Amt. Received*
1	2	3	4	5	6	7	8	9	10	11
0.50	0.00	2.00	5.16	0.00	0.10	7.76	0.00	0.00	7.76	6.02

*Details of received amount are not available.

Total Amount Spent (April, 09 to March, 10) : Rs. 2,49,975

Balance amount (in Rs.) as on 31st March, 2010: Rs. 3,52,025

ICAR Research Complex for NEH Region, Meghalaya

Budget allocation (In Lakhs) for this year (ending by March, 2008)

TA	OTA	RC	Con-tractual services	Work-shop	POL	Total RC (1+2+3+4+5+6)	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
00	00	00	00	00	00	00	00	00	00

Total Amount Spent: (April,09 to March, 10): Rs. 4.102 lakh

Balance amount as on 31st March, 2010: Rs. 1.548 lakh

TA	OTA	RC	Con-tractual services	Work-shop	POL	Total RC (1+2+3+4+5+6	NRC *	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.499	0.000	0.988	2.615	0.000	0.000	4.102	0.000	0.000	4.102

*Though the project was initiated in the year 2009, so far no fund has been received under NRC head.

Project Directorate on Poultry, Rajendranagar, Hyderabad

Budget allocation (In Lakhs) for this year (ending by March, 2008):

TA	OTA	RC	Con-tractual services	Work-shop	POL	Total RC (1+2+3+ 4+5+6	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.5	-	3.00	5.16	0.00	0.10	8.16	1.38	0.00	10.14*

*Total amount released (April, 09 to March 10): Rs 8.88 lakhs

Total Amount Spent: (April, 09 to March, 10): Rs. 5.16 lakhs

Balance amount as on 31st March, 2010 : Rs.3.72 lakhs

TA	OTA	RC	Con-tractual services	Work-shop	POL	Total RC (1+2+3+ 4+5+6	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.49	-	0.35	1.79	0	0.10	2.73	0.99	-	3.72

Tocklai Experimental Station, Tea Research Association, Jorhat, Assam

Budget allocation (In Lakhs) for this year (ending by March, 2010)

TA	OTA	RC	Con-tractual services	Work-shop	POL	Total RC (1+2+3+ 4+5+6	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.50		1.00	4.91		0.1	6.51	1.25*	0.0	7.76

Total Amount Spent: (April, 09 to March, 10): Rs. 5, 60, 118.00

Total amount received upto March 31, 2010: Rs 6, 51, 000.00 (including Rs 5086 as interest)

Balance amount as on 31st March, 2010.Rs 95,968.00

TA	OTA	RC	Con-tractual services	Work-shop	POL	Total RC (1+2+3+ 4+5+6	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
40550		16445	379943			4,36,938	1,23,180		5,60,118.00

Department of Agricultural Meteorology, B.A. College of Agriculture, Anand

Budget allocation (In Lakhs) for this year (ending by March, 2010)

TA	OTA	RC	Con-tractual services	Work-shop	POL	Total RC (1+2+3+4+5+6	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.5	-	1.0	2.21	0.0	0.10	3.81	0.99	0.0	4.80

Total Amount Spent: (April, 09 to March, 10) : Rs. 2, 41,251.00

Balance amount as on 31st March, 2010 :Rs. 2, 38,749.00

TA	OTA	RC	Con-tractual services	Work-shop	POL	Total RC (1+2+3+4+5+6)	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
4,713	0.0	41,564	1,00,253	0.0	0.0	1,46,530	94,721	0.0	2,41,251

Directorate of Soybean Research, Khandwa Road, Indore

Budget allocation (In Lakhs) for this year (ending by March, 2008):

TA	OTA	RC	Con-tractual services	Work-shop	POL	Total RC (1+2+3+4+5+6)	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.50	0.00	2.00	4.20	0.00	0.10	6.80	1.93	0.00	8.73*

Total Amount Received= 8.63

Total Amount Spent: (April, 09 to March, 10): Rs. 4.71913

TA	OTA	RC	Con-tractual services	Work-shop	POL	Total RC (1+2+3+4+5+6)	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.28648	0.00	1.38359	2.10734	0.00	0.00	3.77741	0.94172	0.00	4.71913

Balance amount as on 31st March, 2010=3.91087

Indian Institute of Sugarcane Research, Lucknow, Uttar Pradesh

Budget allocation (In Lakhs) for this year (ending by March, 2008):

TA	OTA	RC	Con-tractual services	Work-shop	POL	Total RC (1+2+3+4+5+6)	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10

Total amount spent in 2008-09

TA	OTA	RC	Con-tractual services	Work-shop	POL	Total RC (1+2+3+4+5+6)	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10

Punjab Agricultural University, Ludhiana

Budget allocation (In Lakhs) for this year (ending by March, 2010)

Pay and Allowances	TA	Contin-gencies	Contractual Services	Work shop	Equip-ments	Vehicle / POL	Total
-	50,000	1,00,000	3,00,000	0.0	0.00	0.0	4,50,000

Expenditure for this year (ending by March 2010)

Pay and Allowances	TA	Contin-gencies	Contractual Services	Work shop	Equip-ments	Vehicle / POL	Total
-	5,259	74,940	1,36,000				2,16,479

Amount sanctioned : Rs 4,50, 000/-

(Revised sanction of Rs 80,000/- not included in university budget due to late receipt)

Amount of actual remittance received during FY 2009-10 :Rs 6,30,000/-

CSK Himachal Pradesh Agriculture University, Palampur

Budget allocation (In Lakhs) for this year (ending by March, 2008):

TA	OTA	RC	Con-tractual services	Work-shop	POL	Total RC (1+2+3+4+5+6)	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.75	-	2.00	5.00	-		7.75	0	nil	7.75
Expenditure under heads 2009-10									
0.46769		0.64732	2.11056	-	-	3.22657	-	-	3.22657

Total Amount Spent: (April, 09 to March, 10): Rs. 3.22657

Balance amount as on 31st March, 2010: Rs.4.52363

Traveling Allowances	OTA	RC	Con-tractual services	Work-shop	POL	Total RC (1+2+3+4+5+6)	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.28231	-	1.35268	2.88844	-	-	3.22657	-	-	4.52363

PUBLICATIONS

Indian Agricultural Research Institute, New Delhi

1. S.D. Singh, S. Mishra, S. Kalpana, B. Chakraborti, V. Kumar and R. Harit. 2009. Effect of high temperature on yield and quality of greengram, chickpea and wheat. Poster presented in National Seminar on Climate Change and Rainfed Agriculture held at CRIDA, Hyderabad from 18-20 Feb. 2009

2. S.D. Singh, S. Kalpana, S. Mishra B. Chakraborti, V. Kumar and R. Harit. 2009. Effect of elevated CO2 on yield and quality of greengram, chickpea and wheat. Poster presented in National Seminar on Climate Change and Rainfed Agriculture held at CRIDA, Hyderabad from 18-20 Feb. 2009 (Awarded best poster presentation)

3. S. Singh. 2009. Variation in physiological traits for thermotolerance in wheat. *Indian J. Plant Physiol*. 14 (4): 407-412

4. S. Singh, S. Mishra and K. Kalpana. 2009. Phenotypic diversity for grain yield and nutritional traits in rice (*Oryza sativa*, L.) IRRN, Los Banos Laguna, Philippines

5. S. Singh, B. Chakrawaorti, P.K. Aggarwal, S. Nagarajan and M. Pal. 2009. Impact of elevated CO_2 on growth and yield of leguminous crops. Page 38-40, In Global Climate Change and Indian Agriculture, edited by P.K. Aggarwal. ICAR, New Delhi

6. S. Singh, B. Chakrawaorti and P.K. Aggarwal. 2009. Impact of elevated temperature on growth and yield of some field crops. Page 45-47, In Global Climate Change and Indian Agriculture, edited by P.K. Aggarwal. ICAR, New Delhi

7. B. Chakrabarti, S.D. Singh, S. Nagarajan, P.K. Aggarwal, H. Prasad and H.B. Choudhary. 2009. Impact of high temperature on pollen sterility and pollen germination in rice and wheat. Page 41-44, In Global Climate Change and Indian Agriculture, edited by P.K. Aggarwal. ICAR, New Delhi

8. S. Singh, R. Harit and V. Kumar. 2009. Impact of global warming agriculture. pp. 17-23 In Climate Change, Ministry of Earth, Govt. of India

9. Shiv Prasad and S. Singh. 2009. Climate change and loss of biodiversity. In: Climate Change, Ministry of Earth, Govt. of India. pp. 24 –35

10. P.K Aggarwal, H. C Joshi, S.D. Singh, Arti Bhatia, N. Jain, Shiv Prasad, Shiv Prasad, Anita Choudhary, N. Gupta and H. Pathak. 2009. Environment and Agriculture. Hand Book of Agriculture 2009, ICAR New Delhi

11. Chaudhary A., Manjaiah K.M., Singh R.K and. Aggarwal, P.K. 2009. Impact of Climate Change (warming) on Microbial Diversity. Research Bulletin of NPCC, ICAR

12. Arti Bhatia, H. Pathak, P.K. Aggarwal, and N Jain. 2009. Trade-off between productivity enhancement and global warming potential of rice and wheat in India. Nutr Cycl Agroecosyst, DOI 10.1007/s10705-009-9304-5

13. Arti Bhatia, S. Sasmal, N. Jain. 2009. Mitigating nitrous oxide emissions from zero till and conventionally tilled soils in wheat. In: Global Climate Change and Indian Agriculture (Ed: P.K. Aggarwal), DIPA ICAR, New Delhi, 2009, 123-128

14. Arti Bhatia and P.K. Aggarwal. 2009. Spatial inventory of greenhouse gases emission from rice and wheat fields in India In: Global Climate Change and Indian Agriculture (Ed: P.K.Aggarwal), DIPA ICAR, New Delhi, 2009, 111-116
15. Chaudhary, A., Manjaiah, K.M., Singh, R.K. and Aggarwal, P. K. 2009. Impact of increase in temperature on microbial diversity .66-92.In Global Climate Change and Indian Agriculture Directorate of Information and Publications of Agriculture, ICAR, New Delhi, India
16. Aditi Srivastava, S. Naresh Kumar and Pramod Kumar Aggarwal. 2010. Assessment on vulnerability of sorghum to climate change in India. Agric. Ecosyst. Environ. Doi:10.1016/j.agee.2010.04.012
17. Kattarkandi Byjesh, S. Naresh Kumar and Pramod Kumar Aggarwal. 2010. Simulating impacts, potential adaptation and vulnerability of maize to climate change in India. Mitigation and Adaptation Strategies for Global Changes. DOI 10.1007/s11027-010-9224-3; 15:413-431
18. S. Singh, Mishra, Kalpana, S. 2010. Phenotypic diversity in grain yield and nutritional traits in rice (*Oryza sativa*, L.). IRRN, Los Banos Laguna, Philippines
19. Chakrabarti, B, Aggarwal, P.K, Singh, S.D, Nagarajan, S. and Pathak, H. 2010. Impact of high temperature on pollen germinatio and sterility in rice: Comparison between basmati and non-basmati varieties. *Crop and Pasture Science*, 61:363-368
20. Arti Bhatia, S. Sasmal, N. Jain, R. Kumar and A. Singh. 2010. Mitigating nitrous oxide emission from soil under conventional and no-tillage in wheat using nitrification inhibitors. Agric. Ecosyst. Environ. doi:10.1016/j.agee.2010.01.004
21. Yadav, D.S. and Chander, S. 2010. Simulation of rice plant hopper damage for developing decision support tools. *Crop Protection* 29: 267-276

Symposium / workshop paper

1. Bhatia, A., Vinay K Singh, S D Singh, B Banerjee, V Kumar, R Harrit, N Jain, and H Pathak. 2009. The impact of elevated carbon dioxide on emission of greenhouse gases from soils under moong and arhar, poster presented at Platinum Jubilee of Indian Society of Soil Science held at IARI, New Delhi, 22-25 Dec, 2009
2. Boomiraj, K., Chakrabarti, B., Aggarwal, P.K., Choudhary, R. and Chander, S. 2009. Impact of climate change on Indian mustard (*Brassica juncea*) in contrasting agro-environments of the tropics. In proceedings of XXXVIII-8/W-3 Workshop on Impact of climate change on Agriculture, 2009 pp. 106-109
3. Chakrabarti, B., Singh, S.D., Singh, B., Harit, R.C. and Kumar, V. 2009. Physiological response of wheat and chickpea crop to elevated CO2 and temperature. In proceedings of National conference on frontiers in Plant physiology towards sustainable agriculture, 5-7 November, 2009, pp. 57
4. Niveta Jain, H. Pathak, A. Bhatia, D.S. Dubey, P. Arora, D. Kumar. 2009. Methane and nitrous oxide mitigation potential of neem oil coated urea fortified with melacins, Paper presentation, Climate change conference held at Gwalior, 11-12 Nov 2009
5. Sigh, S., Chakrabarti, B. Harit, R.C., Kumar, V. and Singh, V.K. 2009. Growth and yield response of different crops to elevated temperature and CO_2. In proceedings of National conference on frontiers in Plant physiology towards sustainable agriculture, 5-7 November, 2009, pp. 60

6. Byjesh, K., R.C. Harit, S. Naresh Kumar and P.K. Aggarwal. 2009. Analysing the response of wheat crop to global warming and atmospheric carbon dioxide rise. In Abstracts: National Conference on Frontiers in Plant Physiology towards sustainable agriculture. ISPP, AAU organized 5-7 Nov, 2009, Jorhat. Pp 62

7. Harit, R.C., Byjesh, K., S. Naresh Kumar, S. D. Singh and P.K. Aggarwal. 2009. Analyzing the effects of intermittent droughts on monsoon cereal crops. In: 2nd India Disaster Management Congress, 4-6 Nov., 2009. NIDM, New Delhi. Pp136

8. Byjesh, K., R.C. Harit, S. Naresh Kumar and P.K. Aggarwal. 2009. Impact analysis of kharif (rainfed) maize yields to future global warming in India. Abstracts, 9th Agricultural Science Congress: Technological and Institutional Innovations for Enhancing Agricultural Income. June 22-24, 2009 at Sher-E-Kashmir University of Agricultural Sciences and Technology of Kashmir, Srinagar. Abs no. 4-15 pp 168

9. Naresh Kumar and P.K. Aggarwal. 2009. Indian Agriculture and Biodiversity in Climate change Scenario. Invited Presentation article: National Symposium on Recent Global Developments in the Management of Plant Genetic Resources, ISPGR, NBPGR, New Delhi 17-18, Dec., 2009 pp 53-62

10. Aggarwal, P.K., S. Naresh Kumar, H. Pathak. 2009. Climate change and wheat production in India: Impacts and adaptation strategies. Invited Presentation article In Consolidating the productivity gain in wheat- An outlook Eds. R.K. Sharma, R. aggarwal, A.M. Singh, A. Sharma and J.B. Sharma (Souvenir), 48th All India Wheat & Barley Research workers' meet. August 28-31, 2009, IARI, New Delhi. pp 26-33

11. Aggarwal, P.K. and S. Naresh Kumar. 2009. Impact of Climate change on horticultural crops. Invited lecture at International Conference on Horticulture (ICH-2009): Horticulture for livelihood security and economic growth, Nov 9-12, 2009, organized by PNASF, UAS and VSIN, Bangalore on 11th Nov, 2009

12. S. Naresh Kumar and P.K. Aggarwal. 2009. Impact of climate change on agriculture in Himalayan river basin. Invited lecture presented at Knowledge Sharing Workshop From Mountains to the Sea: Adapting to Climate Change on November 23-24, 2009, WWF-India Auditorium, New Delhi

13. Niveta Jain, H. Pathak, A. Bhatia, V. Kumar, P. Arora, R. Harit. 2010. Estimation of nitrous oxide flux from soils under cereals, pulses, millets and oilseed crops, poster presented at Indian Science Congress held at Trivendrum, 3-7 January, 2010

14. Niveta Jain, Arti Bhatia, H. Pathak, D.S. Dubey, Pooja Arora, Jagpal Singh. 2010. Impact of sewage sludge and organic manure on methane and nitrous oxide emissions from two rice cultivars in northern India, poster presented at Indian Science Congress held at Trivendrum, 3-7 January, 2010

Central Research Institute for Dryland Agriculture, Hyderabad

1. G.G.S.N. Rao, A.V.M.S. Rao, V.U.M. Rao, M. Vanaja, M. Srinivasa Rao, K.V. Rao, S. Desai and Ch. Srinivasa Rao. 2009. Impact, Adaptation and vulnerability of rainfed agriculture to climate change: Research at CRIDA. Indian Journal of Dryland Agricultural Research and Development. 24 (2): 10-20

2. Satyanarayana, T., Rao, A.V.M.S., Manikandan, N., Rao, V.U.M. and Rao, G.G.S.N. 2009. Impact of increasing temperature on growing period of wheat crop at Hisar. *Agrometeorology J.* 11 (Special Issue): 33 – 36

3. Rao, V.U.M., Manikandan, N., Singh, N. P., Bantilan, M.C.S., Satyanarayana, T., Rao, A.V.M.S. and Rao, G.G.S.N. 2009. Trends in heavy rainfall events in Anantapur and Mahabubnagar districts of Andhra Pradesh. *Agrometeorology J.* 11 (Special Issue): 195 – 199

4. Manikandan, N., Rao, G.G.S.N., Rao, A.V.M.S., Rao, V.U.M. and Satyanarayana, T. 2009. Variations in moisture regime at selected locations over India. *Agrometeorology J.* 11 (Special Issue): 200 – 203

5. Srinivasa Rao, M., Srinivas, K., Vanaja, M., Rao, G.G.S.N., Venkateswarlu, B and Ramakrishna, Y.S. 2009 Host plant (*Ricinus communis* Linn) mediated effects of elevated CO_2 on growth performance of two insect folivores *Current Science.* 97(7):1047-1054

6. Srinivasa Rao, M., Ranga Rao, G.V and Venkateswarlu, B. 2010. Impact of climate change on insect pests in *'Lead papers'* of National Symposium on Climate change and Rainfed Agriculture organized by Indian society of Dryland agriculture and Central Research Institute for Dryland Agriculture during 18-20, February, 2010.pp 43-54

Communicated

1. M. Vanaja. Influence of 700 ppm of CO_2 on yield and its components of red gram (*Cajanus cajan*)

2. M. Vanaja. Yield and harvest index of short and long duration grain legume crops under twice the ambient CO_2 levels

Presentations in Conferences/ Symposia/ Seminars

1. M. Maheswari, M. Vanaja, Arun K. Shanker and B. Venkateswarlu. 2010. Strategies for developing climate ready crop varieties. Presented lead paper in technical Session II: Impacts, Adaptation and Mitigation Strategies in Dryland Cropping Systems, at National symposium on "Climate Change and rainfed Agriculture" held at CRIDA during 18-20 February 2010. pp 27-36

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